HC 402.8 .4

28.F.39.

Digitized by the Internet Archive
in 2025

https://archive.org/details/refractioofeyean0000kenn

THE REFRACTION OF THE EYE AND THE ANOMALIES OF THE OCULAR MUSCLES

THE REFRACTION OF THE EYE AND THE ANOMALIES OF THE OCULAR MUSCLES

BY

KENNETH CAMPBELL, M.B. Edin., F.R.C.S. Eng.

Surgeon to the Western Ophthalmic Hospital

Surgeon-Oculist to His Highness the Maharajah and Gaekwar of Baroda

'True Science is in itself simple, and should be explained in as simple and definite language as possible.'—Professor Tait

NEW YORK

WILLIAM WOOD & COMPANY

MDCCCCIII

3221.

BOSTON MEDICAL
JUN 2 1903
LIBR

PREFACE

In the following pages I have endeavoured to carry out the principle laid down in the thesis of Professor Tait that: 'True science is itself simple, and should be explained in as simple and definite language as possible.'

My best thanks are due to Mr. Ernest Crosland, Mr. Edwin Holthouse and Miss Turner for their able assistance.

Wimpole Street,
Cavendish Square, W.
February, 1903.

CONTENTS

CHAPTER		PAGE
I.	REFRACTION AND REFLECTION	1
II.	FORMATION OF THE RETINAL IMAGE	28
III.	ACCOMMODATION AND CONVERGENCE	43
IV.	THE OPHTHALMOSCOPE	57
V.	THE NORMAL FUNDUS AS SEEN WITH THE OPHTHALMOSCOPE	85
VI.	AMETROPIA	95
VII.	MYOPIA	106
VIII.	ASTIGMATISM	125
IX.	PRESBYOPIA	140
X.	ANISOMETROPIA	145
XI.	POSITION OF SPECTACLE GLASSES	147
XII.	ASTHENOPIA	152
XIII.	STRABISMUS	175
	APPENDIX	211
	INDEX	213

BOSTON MEDICAL
JUN 2 1903
LIBRARY.

REFRACTION AND ACCOMMODATION OF THE EYE

CHAPTER I

REFRACTION AND REFLECTION

Optical Principles.

Optics is that branch of physical science which treats of the natural properties of light and the phenomena of vision.

Sight or *vision* is the mental perception of specific energy, and is no more an entity than taste, smell, hearing, or touch.

Light is that form of energy which is the cause of sight, but it is a convenient word to use as signifying *rays of light*, a term which indicates the straight lines along which the undulations of the ether, that are of a similar type to the waves of the sea, travel.

Accordingly, the terms *light* and *rays of light* (*radius*, a ray) will be used as synonymous.

An object is visible either because it is *incandescent* or *self-luminous*—*i.e.*, gives out its own light (*e.g.*, the sun); or through being illuminated by *reflection* (*e.g.*, the moon) from a self-luminous body—*i.e.*, gives out light received from another source.

From every point of the surface of a luminous body light is radiated in straight lines in all directions.

A collection of rays grouped around a central, or an *axial*, ray, with its cross-section circular in outline, is technically known as a *pencil* or *cone of light*, and according

as the separate rays are travelling at equal distances from each other, separating from one another, or approaching each other, they are designated *parallel*, *divergent*, or *convergent* rays.

A *homocentric pencil* (*homos*, same, *kentron*, circle) is a collection of rays proceeding from or to a single point F.

FIG. 1.—A HOMOCENTRIC PENCIL.

The rays of a *homocentric pencil* cannot, in the strict geometrical sense, ever actually become parallel, but in physiological optics the constituent rays *are assumed to be parallel at a distance of* 20 *feet* or more from the point of origin.

Medium is the term indicating the vehicle of transmission of light, and may be either *dense* or *rare*.

A *dense medium* is one whose molecules are so closely packed that the intermolecular spaces are small.

A *rare medium* is the converse of this.

A *homogeneous* (*homos*, same, *genos*, kind) or *uniform medium* is one whose chemical composition and density are the same throughout.

A *heterogeneous* (*heteros*, other, *genos*, kind) *medium* is the converse of this.

A *transparent body* is one through which the *form* of objects can be distinctly seen—*e.g.*, glass, water, etc.

A *translucent body* is one through which *light* only can be seen—*e.g.*, frosted glass, etc.

An *opaque body* is one that is impervious to the rays of light; it is a relative term, however, for if a sufficiently thin section be made of an opaque body, such as a metal, some light will be able to pass through—*e.g.*, gold transmits a greenish light.

Rectilinear Propagation of Light.

Rays of light while confined to the same uniform medium advance in straight lines and do not deviate; they continue to do so until entering another medium of *different* refractive index (*q.v.*).

Rays of light impinging upon an object may be:

(*a*) in part *absorbed*,
(*b*) in part *refracted*,
(*c*) in part *reflected*.

REFRACTION.

Refraction (*re*, back, *frango*, I break) is that branch of optics which treats of the laws relating to the transmission of luminous rays through transparent media, and it is in accordance with these laws that images of external objects are formed on the retina.

As already stated, a ray of light, while confined to the same uniform medium, advances in a straight line. A ray passing *perpendicularly* from one medium into another of different refractive index also does so without any change of direction. A ray passing *obliquely* from one medium to another of different refractive index is bent at an angle from its original path, *the bending taking place at the surface of separation* of the media; this change of direction is called *refraction*.

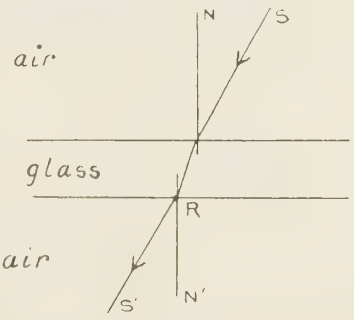


FIG. 2.—PATH OF A RAY OF LIGHT THROUGH A PLATE.

A ray of light (S) passing *obliquely* from a rarer into a denser medium is refracted *towards* the normal (N)—*i.e.*, the perpendicular to the surface drawn through the point of incidence or the point of emergence; conversely, a ray (S) passing from a denser into a rarer medium is refracted *from*

the normal (N). In both cases the deviation is in proportion to the difference between the refractive indices of the two media.

Laws of Refraction.

Let R I represent a ray of light in air incident (*incido*, I fall upon) at I upon the surface of water. Draw the normal N I P. The acute angle R I N is called *the angle of incidence*. The acute angle S I P is called *the angle of refraction*. Continue the direction of R I to R′. The angle R′ I S is called the *angle of deviation*, because it measures the degree of deviation of the ray from its path. With I as centre describe a circle. From the points where the circle cuts the incident and refracted rays draw perpendiculars to the normal. The perpendicular R C is plainly equal to R′ P′, which is greater than S P. *The ratio of these perpendiculars has a constant value for the same two media.*

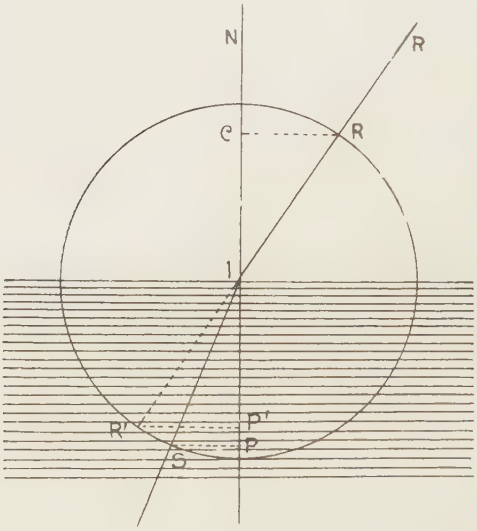


FIG. 3.—TO ILLUSTRATE THE INDEX OF REFRACTION, $\mu = \frac{C\,R}{S\,P}$.

The incident ray, the refracted ray, and the normal are all in the same plane, and there is a definite ratio between the angle of incidence and the angle of refraction—that is, for the same two media the sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction.

This is the fundamental law of refraction. The constant ratio is called the *refractive index* (usually designated by the Greek letter μ) from the first medium to the second.

Generally speaking, the refractive index of a medium is greater as the density is greater, so that the greater the density of any medium the greater is its refractive power.

On passing from the air into water, the ray of light is so refracted that the sine of the angle of incidence is to the sine of the angle of refraction as 4 : 3—*i.e.*, the refractive index $= \frac{4}{3} = 1{\cdot}33$.

Refractive index from air into glass $= \frac{3}{2} = 1{\cdot}5$.

The refractive index for any two media represents the relative velocities of light in the media—*e.g.*,

$$\frac{\text{velocity of light in air}}{\text{velocity of light in glass}} = \frac{3}{2} = 1{\cdot}5.$$

Refraction through a Prism.—An ophthalmic prism is a wedge-shaped piece of glass or other transparent substance contained between two plane surfaces which intersect at the edge or *apex*, opposite to which is the thickest part, or *base*. The cross-section presents the form of a triangle, and if the section be at right angles to the refracting surfaces it is called a *principal plane*, or *section*. The angle contained between the two plane surfaces is known as the *refracting angle* of the prism, (*a*).

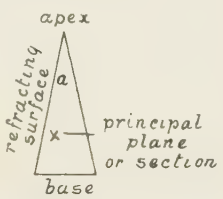


FIG. 4.

The refractivity of a prism depends upon—
- (*α*) The size of the refracting angle.
- (*β*) The refractive index of the substance from which it is cut.
- (*γ*) The position with respect to the incident light.*

A ray of light, passing from a rarer medium (*e.g.*, air) and incident at right angles to the surface of a prism, undergoes refraction only at the point at which it leaves. Rays incident in any other direction undergo refraction both on

* There is a particular position for every prism with respect to the incident light in which the deviation produced is a minimum. This is the symmetrical position—*i.e.*, that in which the light traverses the prism parallel to its base. It is known as that of *minimum deviation;* but in the case of thin prisms, which are here treated of, the effect of position is negligible.

entering and leaving (except in the case of internal normal incidence).

Let *a b c* represent a prism of which *a* is the refracting angle. A ray D′ E′ incident at E′ is refracted *towards* the normal at E′. On emerging from the prism at E the ray is refracted *from* the normal, taking the direction E D. If the prism is denser than the surrounding medium the rays are always refracted *towards the base*. Produce D E and D′ E′ to meet at G. The angle F G D′ is called *the angle of deviation*; it is the angle between the original and final direction of the ray.

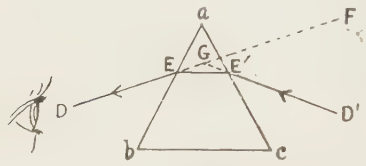


FIG. 5.—VISION THROUGH A PRISM; APPARENT DISPLACEMENT TOWARDS APEX.

Monochromatic parallel rays entering a prism emerge parallel. The relative positions of the rays of a pencil of light being unchanged in passing through a prism, they cannot come to a focus; *therefore a prism cannot form a real image*.

The effect of looking through a prism is that an object appears to be displaced to a position *towards the apex*, the degree of displacement depending on the size of the refracting angle *a* and μ. Hence an observer at D looking at an object at D′ would see it apparently displaced to F.

Note.—The eye takes no cognizance of any change of direction which has been suffered by the light, and therefore always sees things in the direction in which light from them enters it.

Terminology of Prisms.

The strength or refractivity of a prism is generally expressed by the number of degrees contained in its refracting angle *a*, this being scratched on the outside.

In the formula—

$$d = (\mu - 1)\, a.$$

d = deviation.

a = refracting angle of the prism.

$$\mu \text{ (refractive index)} = \frac{\text{velocity of light in air}}{\text{velocity of light in crown-glass}} = 1{\cdot}528.$$

Hence $\mu - 1$ is approximately one-half. So that the deviation produced by a prism is very nearly half its own refracting angle. For example, a prism of 10° produces a deviation of about 5°.

This method is very convenient, and in spite of criticisms is the one in general use for designating the strength of a prism. For clinical purposes only weak prisms are employed (rarely exceeding 4°), as stronger ones cause chromatic aberration, and are unpleasantly heavy. *Crown-glass* is almost invariably used, as it causes much less chromatic aberration than flint-glass.

PRISM-DIOPTRES AND CENTRADS.

Let C O A be a ray of light, and C O B its path after refraction through a prism placed at O. The angle A O B is the deviation.

Let the length of O A be 1 metre. Under these conditions, if A B is 1 cm., the strength of the prism is 1 prism-dioptre, 1 P.-D., or 1^{Δ}; if A B is 2 cm., the strength of the prism is 2 prism-dioptres, 2 P.-D., or 2^{Δ}, and so on.

Now, for such a small angle as A O B, the *arc* A B is almost coincident

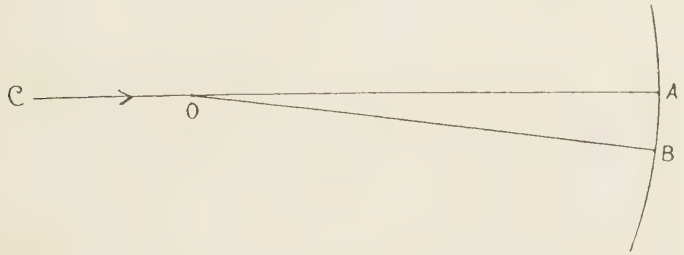


FIG. 6.

with the *straight line* A B (*i.e.*, the chord). If the *arc* A B were as long as the radius O A, the angle A O B would be the unit angle (in circular measure), called *the radian* (57·2958°); but since A B is $\frac{1}{100}$ of O A, the angle A O B is $\frac{1}{100}$ of a radian (*i.e.*, rather more than half a degree), and this angle is called *a centrad.* Hence the strength of a prism can be expressed in centrads, as suggested by Dennett, and is notated 1 ∇, 2 ∇, etc.

It will be seen from this that for small angles, prism-dioptres and centrads are the same thing, but this is not true for angles where the arc is appreciably longer than the chord.

USES OF PRISMS.

1. **To Test the Power of the Extra-Ocular Muscles (Fusion Power).**—The effect of a prism held before the eye is to displace the

image belonging to that eye from its yellow spot to another part of the retina, *the mental image being moved in the direction of the apex of the prism.* The strength of the different muscles may be ascertained by finding what prism they are respectively capable of overcoming, so that binocular single vision shall result. For example, place a pair of prisms in front of the eyes with their bases *outwards:* the strongest pair which, when the eyes are directed to a distant object (*e.g.*, a lighted candle), does not cause diplopia, measures the power of convergence.

2. **In the treatment of diplopia,** to cause the displacement of the 'false' image in such a way that it may be made to fall upon the yellow spot of the deviating eye, and so be fused with the 'real' one in the other eye.

In the deviating eye R the yellow spot, *ys*, is turned towards *f*, and so two images of *ob* are seen, the image being on the yellow spot in the left eye, L, but on another part of the retina, *x*, in the right R. The prism placed in front of this eye *refracts the rays towards its base*, thus causing the image of the object, *ob*, to fall upon the yellow spot.

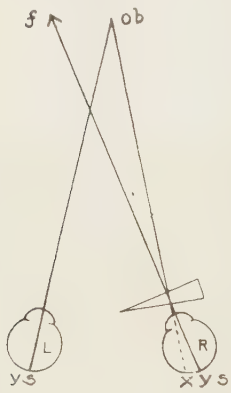


FIG. 7.— TREATMENT OF DIPLOPIA. FALSE IMAGE DISPLACED BY A PRISM SO AS TO FALL ON YELLOW SPOT.

3. **To strengthen weak extra-ocular muscles** by throwing moderate additional work on them.

4. **To detect Malingerers.**—This is called the *diplopia-test*, as it depends upon the principle that an object seen through a prism appears to be displaced towards its apex. In one compartment of the spectacle trial-frame place a prism of 8° or 10°, with base (preferably) upwards or downwards, and cover it by an opaque screen. Place the subject to be examined opposite the distant test-types, and arrange the spectacle-frame so that the side containing the prism is in front of the alleged blind eye; then request him to read the letters with the uncovered eye, and whilst doing so confuse him as much as possible by cross-examination, so putting him off his guard. Now suddenly withdraw the cover, when at once double-vision will result if he be a malingerer, for the test-types will appear duplicated by another similar set coming into view, and occupying a situation in the direction of the apex of the prism.

The other uses of prisms are discussed in the chapters on Heterophoria and Strabismus.

Refraction at Spherical Surfaces.

Lenses.—A lens is a circular portion of a transparent refracting body bounded by two surfaces, which may be both spherical or one plane. Lenses are classified according to their form, and only those in general use in ophthalmic practice will be noticed.

The two chief kinds are :

1. **Spherical** { (*a*) *biconvex.* (*b*) *biconcave.*
2. **Cylindrical.**

1. SPHERICAL.

(*a*) **Biconvex Lenses.**—A *biconvex lens* is composed of equal segments of equal spheres.

The centres of the spheres of which the bounding surfaces are part are called the *centres of curvature;* the straight line joining the centres of curvature is called *the principal axis* (P A), and the mid-point of this line the *optical centre* (C). *The optical centre has the property that any ray passing through it suffers no deviation. A secondary axis* is any straight line, other than the principal axis, which passes through the optical centre (S A_1 in the figure).

A ray incident along the principal axis suffers no deviation, because its incidence is normal to both surfaces. A ray passing along a secondary axis (S A) emerges parallel to its original direction. Although not strictly speaking coincident, the amount of lateral displacement is so slight, owing to the comparative thinness of the lenses used, that with sufficient accuracy, for ordinary purposes, it may be disregarded, and hence, in physiological optics, it is convenient to assume that all rays passing through the optical centre of a lens do so without deviation, the incident and emergent ray forming one straight line.

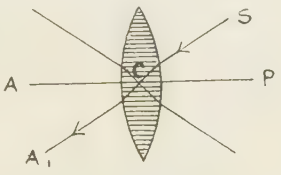


FIG. 8.—PRINCIPAL AND SECONDARY AXES.

Rays transmitted through a convex lens are refracted *towards* its principal axis, the rays incident further from the axis being more deviated because their incidence is more oblique.

Rays striking upon one side of a convex lens in a direction parallel to the principal axis are brought to a point on the principal axis at the other side (Fig. 9). This point is termed the *principal focus*, F, and its distance from the optical centre

indicates the *focal length* of the lens. In the same way rays parallel to a secondary axis are brought to a focus at a

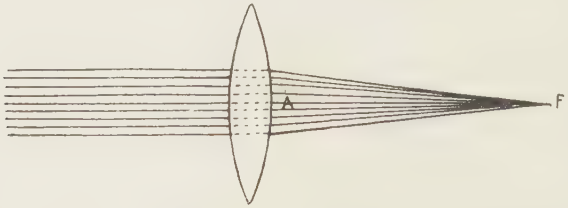


FIG. 9.—THE PRINCIPAL FOCUS OF A CONVEX LENS.

point on that axis, S R and T being repectively the foci of the parallel rays S R and T (Fig. 10).

Convex lenses are sometimes called *positive* or *plus* (+), because they have the power of collecting the rays at a real or positive focus, in contradistinction to concave lenses, which cause the rays to diverge from one another in such a manner as to make them appear to come from a *negative* (−) or *virtual* focus.

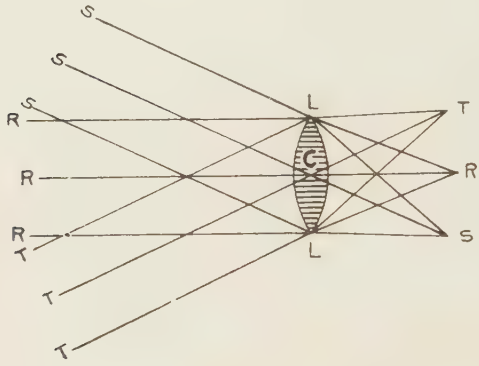


FIG. 10.

Conjugate Foci.—Rays diverging from the principal focus and passing through the lens emerge parallel. Rays

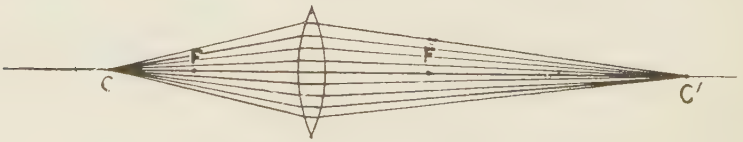


FIG. 11.—CONJUGATE FOCI.

diverging from a point C (Fig. 11) on the principal axis at a greater distance than the principal focus F will be brought

to a focus on the other side of the lens at C′. C and C′ are interchangeable, or *conjugate foci*.

Rays diverging from a point C (Fig. 12) nearer than the principal focus F continue to diverge after leaving the lens as if they came from a point C′ on the same side of the lens from which they started. C and C′ are conjugate foci, C being a real and C′ a virtual or negative focus.

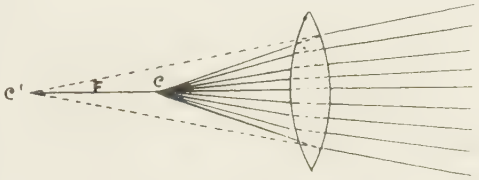


FIG. 12.—VIRTUAL FOCUS.

Geometrical Construction for Image.—An image may be defined as the sum of the focal points of that face of an object from which light passes through the lens, each focal point corresponding to a point on the object.

An object O B is situated on one side of a convex lens further away than F. From its extremity O draw a line representing a ray passing through the optical centre C. This will form a secondary axis, and will emerge undeviated. From the same point draw another line to represent a ray

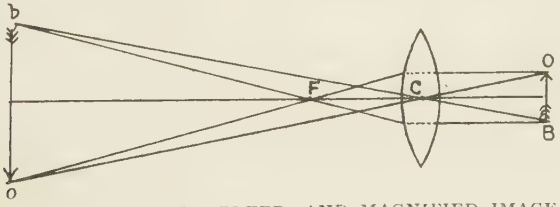


FIG. 13.—REAL, INVERTED, AND MAGNIFIED IMAGE.

parallel to the principal axis of the lens. This will be refracted by the lens, and on emergence will pass through the principal focus F and meet the other ray at *o*. This point *o* will form the conjugate focus to the point O. In the same manner the rays from the point B will unite in a conjugate focus at *b*. A real image of O will be formed at *o*, and a real image of B at *b*. The intermediate points of the object will have their own conjugate foci, and will form images in corresponding positions between *o* and *b*, the result being an

enlarged and inverted real image of the object O B. The size of this image will be determined by the size of O B and its distance from the lens.

If the object O B is situated between the lens and its principal focus, the image will be virtual, upright, and enlarged.

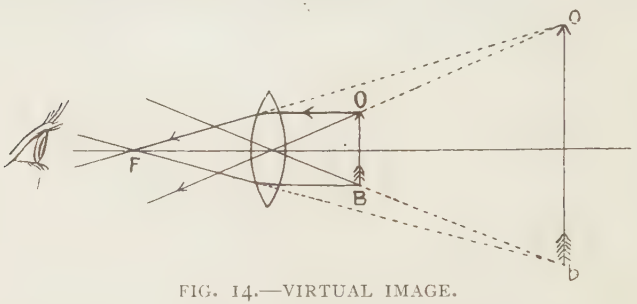


FIG. 14.—VIRTUAL IMAGE.

From O draw the two straight lines as in previons construction, the one passing through the optical centre, and the other parallel to the principal axis. On passing out they will take a direction as if coming from a point *o*.

Deal similarly with B. A person looking through the lens at O B will see a virtual, upright, and enlarged image of it at *o b*.

SUMMARY OF RESULTS FOR CONVEX LENSES.

Distance of Object.	Distance of Image.	Character of Image.
Infinite.	F.*	Real, inverted, less.
Greater than 2 F.	Between F. and 2 F.	Real, inverted, less.
2 F.	2 F.	Real, inverted, same size.
Between 2 F. and F.	Greater than 2 F.	Real, inverted, enlarged.
Less than F.	On same side as object. Greater than F.	Virtual, erect, enlarged.

The positions of conjugate foci and images may be calculated from the formulæ :

$\frac{1}{d}+\frac{1}{d'}=\frac{1}{f}$ for convex lens and concave mirror (f = real focal length).

$\frac{1}{d}-\frac{1}{d'}=\frac{1}{f}$ for convex lens and concave mirror (f = virtual focal length).

$\frac{1}{d'}-\frac{1}{d}=\frac{1}{f}$ for concave lens and convex mirror (f = virtual focal length).

$$\frac{\text{The size of image}}{\text{The size of object}}=\frac{\text{distance of object } (d).}{\text{distance of image } (d').}$$

* F. denotes focal length of lens.

Cardinal Points.—It has been shown by Gauss, in order to simplify the problems connected with various lens-systems, that in every system of refracting media there may be assumed to be certain *cardinal points* to which the whole system may be reduced. If these points are known, a calculation can be made of the size and position of the image of any given object.

In the accompanying drawing the cardinal points of an ordinary biconvex lens are shown, but, with certain modifications, the statements apply to any lens-system.

Properties of Cardinal Points.—The *principal points* (or optical centres) H_1 and H_2. Any ray passing through one of these points will, after refraction, emerge parallel to its former direction, but as if it had passed through the other, as in Fig. 16. All secondary axes pass towards the first point H_1, and to and from the second point H_2 in a direction parallel to their original direction. Planes passing vertically through the axis at these points are *principal planes.*

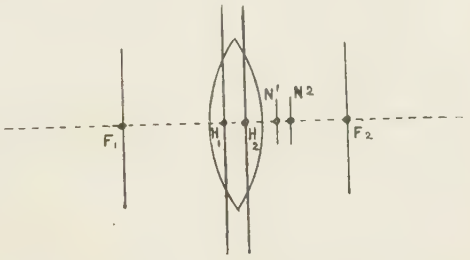


FIG. 15.—CARDINAL POINTS.

The *first focal point* F_1 has the property that every ray which passes through it, after refraction, becomes parallel to the axis.

The *second focal point* F_2 has the property that every parallel ray, after refraction, passes through it. Planes passing perpendicularly to the axis through these focal points are termed *focal planes.*

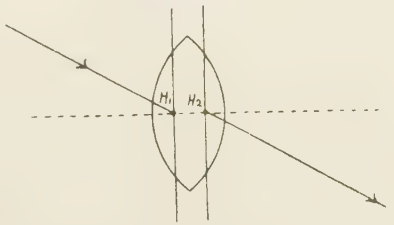


FIG. 16.—SECONDARY AXES IN REFERENCE TO PRINCIPAL PLANES.

The *nodal points,* N_1 and N_2. These points are identical with the 'principal points' if the media on either side of

the lens are of the same refractive indices, but if the lens, or lens-system, be surrounded by two different media—for example, by air in front and water behind, as in the case of the eye—the optical centres become displaced backwards along the axis *towards the denser medium*—that is, from H_1 H_2 to N_1 N_2. A ray which in the first medium is directed to the first nodal point N_1 will pass, after refraction, through and from the second nodal point N_2 in a direction parallel to its first direction. *The paths of all such rays are secondary axes.*

These nodal points are of special interest in determining the size of the retinal image, since all the secondary axes drawn from the various points of an object to corresponding points of the image must pass through them.

From these properties of the cardinal points the construction and position of the image can be determined.

Let O be a point on object O X. Draw O P parallel to the axis to meet the second principal plane at P. P G will represent this ray after refraction. Draw the secondary axis O C to the first nodal point N_1, and draw D E from the

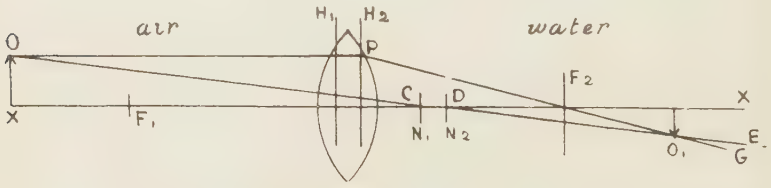


FIG. 17.—CONSTRUCTION OF IMAGE BY USE OF CARDINAL POINTS. XX=OPTICAL AXIS.

second nodal point parallel to O C. The image of O will be at the point of intersection of the two refracted rays P G and D E—viz., at O_1.

In this figure it is assumed that the surrounding media are of different densities—viz., in front of the lens is air, behind the lens water; otherwise, if the surrounding media were of equal density, the *principal points* and the *nodal points* would be identical.

(*b*) **Biconcave Lenses.**—A biconcave lens is thinner in the middle than at the edges. The rays transmitted through a concave lens are refracted *from* the principal axis, the rays

incident further from the axis being more deviated because their incidence is more oblique.

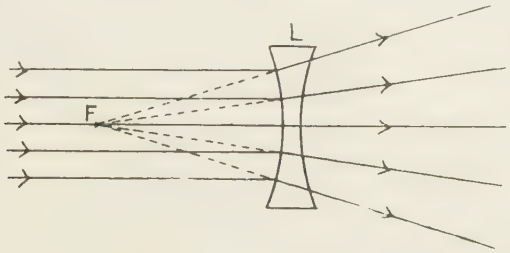


FIG. 18.—PRINCIPAL FOCUS OF A CONCAVE LENS (VIRTUAL).

The terms optic axis, optical centre, and secondary axis have the same significance when applied to concave lenses as to convex.

Parallel rays falling on a concave lens emerge divergent (Fig. 18), and if they be continued in a backward direction they will meet at a point F. This point F is the *principal focus*, and is *negative* (−) or *virtual*.

Images formed by concave lenses are always *virtual*, *erect*, and *smaller* than the object.

Let O B (Fig. 19) represent the object, F the focus, and C the optical centre. A ray coming from O parallel to the principal axis will diverge as if coming from F. This line cuts the secondary axis O C at *o*. Rays coming from O emerge from the lens as if they came from *o*. *o* is the virtual image of O,

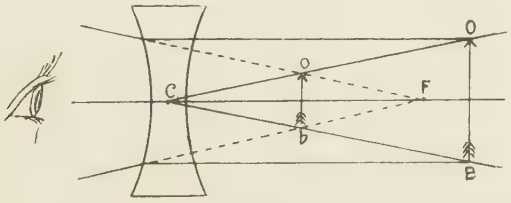


FIG. 19.—MINIFYING EFFECT OF A CONCAVE LENS.

and *b* of B. The intermediate points of the object O B will form images in corresponding positions between *o* and *b*, the result being a virtual, erect, and diminished image of the object O B. This is the case for all images formed by concave lenses, irrespective of the position of the object.

The Numbering of Lenses.

The *strength* or *power* of a lens depends upon two factors:

(*a*) The refractive index of the glass from which it is ground.

(*b*) The radii of curvature of its surfaces.

By international agreement (1879) lenses are numbered on the principle of the metric system.

The *metre* (= 1,000 mm. = 100 cm. = 39·37 inches)* has been adopted as the standard unit, the glass, which has a focal length of 1 *metre*, being called a lens of 1 *dioptre*, or for brevity 1 D.

Lenses are therefore described by giving to each the reciprocal of its focal length in metres, and placing before this number the sign + or − to indicate whether it has a positive or a negative focus for parallel rays. Thus a + 4 D. lens is a convex lens of 25 cm. or 10 inches focal length.

The lenses employed in ophthalmic practice are arranged in a graduated series in the 'trial-case,' numbered from 0·25 D. to 20 D., with the refractive power of each represented by such a numeral.

To find the Focal Length of a given Lens.—If it be required to find the focal length of a particular lens, given the strength in the above notation, divide 100 (100 cm. = 1 metre = 40 inches) by the number of the lens in question, when the quotient will show the focal length in centimetres or inches.

E.g., What is the focal length of a + 5 D. lens?

$$\frac{1 \text{ D.} = 100 \text{ cm.} = 40 \text{ inches (nearly)}}{5 \text{ D.}} = 20 \text{ cm. or } 8 \text{ inches.}$$

Of a 0·25 D. lens?

$$\frac{1 \text{ D.} = 100 \text{ cm.} = 40 \text{ inches}}{0{\cdot}25 \text{ D.}} = 400 \text{ cm. or } 160 \text{ inches.}$$

* To be strictly accurate, the metre contains 39·3708 inches, but the round number 40 is convenient to use without introducing any material error into the calculations.

Decentration of Lenses.

If spherical lenses are necessary, but the effect of a prism is required as well, this result can be attained by displacing the optical centre of the lens away from the geometrical centre.

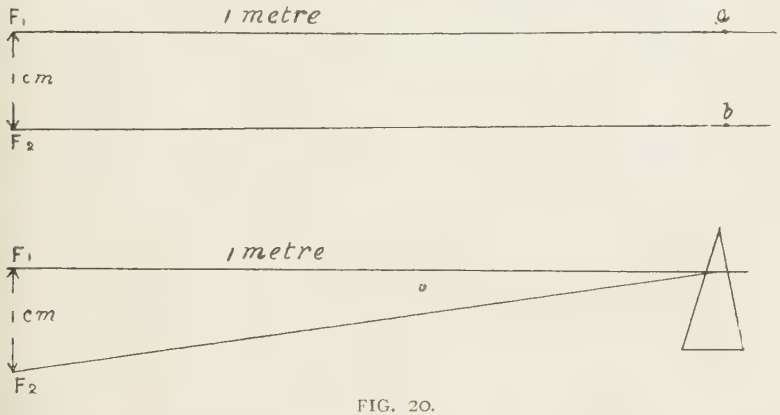
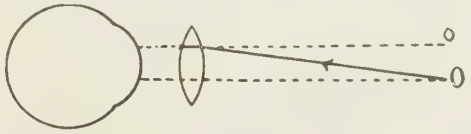
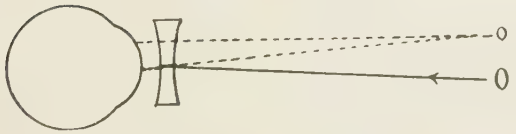


FIG. 20.

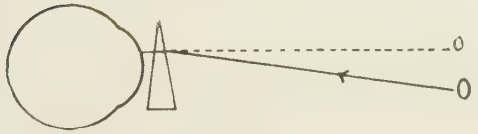
Let *a* (Fig. 20) be the optical centre of the lens (+1 D.),



+LENS DECENTRED IN OR UP.



−LENS DECENTRED OUT OR DOWN.



PRISM WITH BASE IN OR UP.

FIG. 21.—DIAGRAMS SHOWING HOW DECENTRED LENSES ACT AS PRISMS. AN OBJECT AT O IS SEEN AT O.

and F_1 its principal focus. If the optical centre be moved to the position *b*, then F_1 goes to F_2.

a F_1 is 1 metre, and suppose *a b* = 1 cm., then we have the effect which would be produced by a prism of 1 p.-d., as shown in the second figure. For example, if a + spherical glass be decentred in, or a − glass be decentred out, the effect is that of a prism with its base *in*. So, likewise, if a + lens be decentred up, or a − lens be decentred down, the effect is that of a prism with its base *up*.

Rules for Correction by Decentred Lenses.

A spherical lens of either +1 D., or −1 D., in order to produce the effect of a prism of 1° (or deviation of $\frac{1}{2}$°), must be decentred 8·7 mm. (The arc which at 1 metre subtends an angle of $\frac{1}{2}$° is 8·75 mm., as shown below.) Accordingly, knowing the value of the prism necessary, we multiply by 8·7,

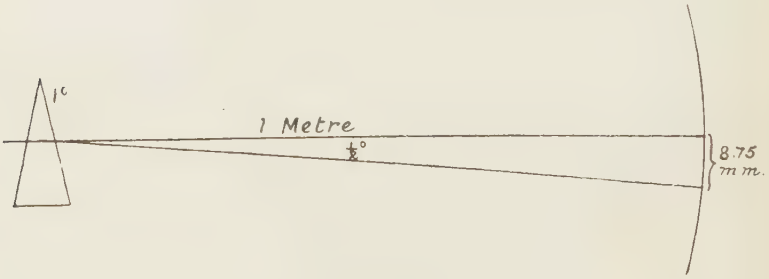


FIG. 22.

and divide the product by the strength of the lens required —*e.g.*, the displacement produced by a + 3 D spherical lens decentred so as to have the effect of a prism of 2° (base in)

$$= \frac{2 \times 8{\cdot}7}{3 \text{ D}} = 5{\cdot}8 \text{ mm.}$$

Hence in this case the +3 D. lens, in order to possess the added value of a prism of 2°, must be decentred 5·8 mm. *in*.

2. CYLINDRICAL.

A *cylinder* is defined as the form traced out by the rotation of a rectangle round one of its sides—*e.g.*, by the rotation of *p q r s* round *p s* (Fig. 23).

A *convex* cylindrical lens is a circular-shaped portion cut from a vertical section of a solid glass cylinder (Fig. 24).

A *concave* cylindrical lens is cut as represented in Fig. 25. The axis *ax*, which is denoted by a linear scratch on the lens, is in a plane passing through the line *a x* and the axis of the cylinder *p s* (Fig. 23); it is at right angles to the meridian of maximum curvature (*c c c*, Fig. 23).

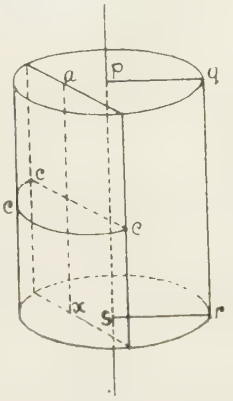


FIG. 23.—DERIVATION OF CYLINDRICAL LENS.

A cylindrical lens has the property that the rays passing through it are refracted unequally in different meridians, so that it has no common focal point, *but a line of foci parallel to its axis*, F F_1 (Figs. 26, 27).

Rays incident in the plane of the axis pass through unrefracted; those incident in a plane at right angles to the axis undergo the maximum refraction; whilst those incident upon the intervening meridians will undergo a proportionate degree of refraction ranging from a maximum to zero; *e.g.*—

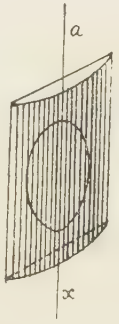


FIG. 24.—CONVEX CYLINDRICAL LENS.

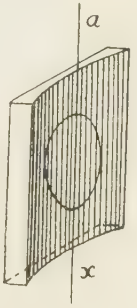


FIG. 25.—CONCAVE CYLINDRICAL LENS.

+4 D. cylinder is equivalent to 0 at axis;

+4 D. cylinder at right angles to axis is equivalent to a +4 D. lens;

+4 D. cylinder is equivalent to 2 D. in meridian of 45°.

A lens cylindrical on one side and plane on the other is

termed a *plano-cylinder*, and is the kind generally used in ophthalmic practice. Sometimes it is necessary to grind a glass cylindrical on one side (convex or concave) and spherical (convex or concave) on the other; this kind of lens is known

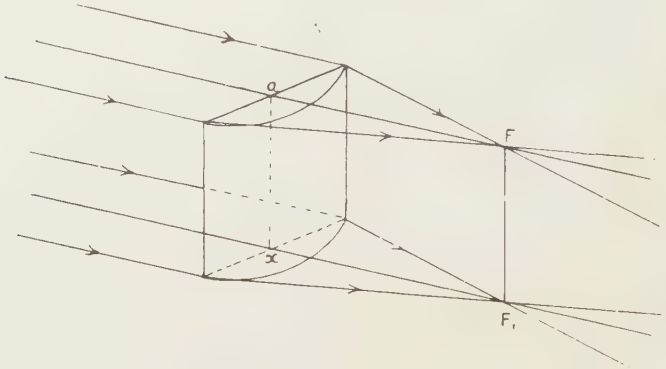


FIG. 26.—REAL LINEAR FOCUS F F_1 OF +CYLINDRICAL LENS.

as a *sphero-cylinder*. Such a lens has two foci, both of them linear, the one linear focus parallel to the axis of the cylinder and situated at a distance corresponding to the refractive

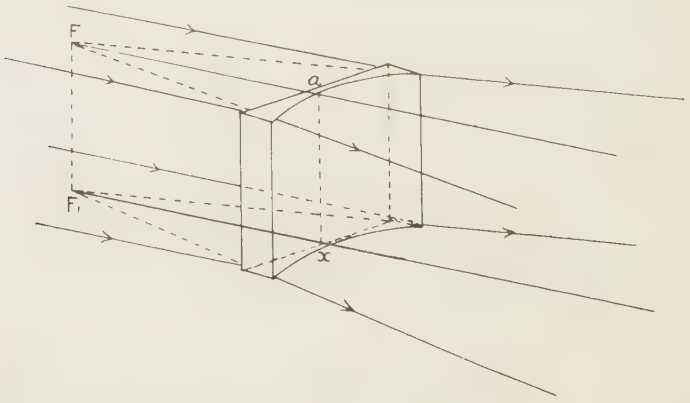


FIG. 27.—VIRTUAL LINEAR FOCUS F F_1 OF −CYLINDRICAL LENS.

power of the united lenses, and the other at right angles to the axis of the cylinder and situated at a distance corresponding to the refractive power of the cylinder itself; *e.g.*, in this combination—

$$\frac{+2 \text{ D. spherical}}{+2 \text{ D. cylindrical axis vertical}},$$

the first linear focus would be vertical and situated at a distance of

$$\frac{1 \text{ metre} = 40 \text{ inches}}{+4 \text{ D.}} = 10 \text{ inches},$$

and the second linear focus would be horizontal and situated at a distance of

$$\frac{1 \text{ metre} = 40 \text{ inches}}{+2 \text{ D.}} = 20 \text{ inches}.$$

Crossed cylinders—i.e., with the axes set at right angles—are rarely used; if of equal power they act as spheres (Fig. 28).

Cylindrical lenses are numbered in accordance with the refractive power of the meridian of maximum curvature.

Inasmuch as cylindrical lenses refract unequally in different meridians the rays incident upon them, they are used to correct the inequality of the meridians of the eye in regular astigmatism (*vide* chapter on Astigmatism).

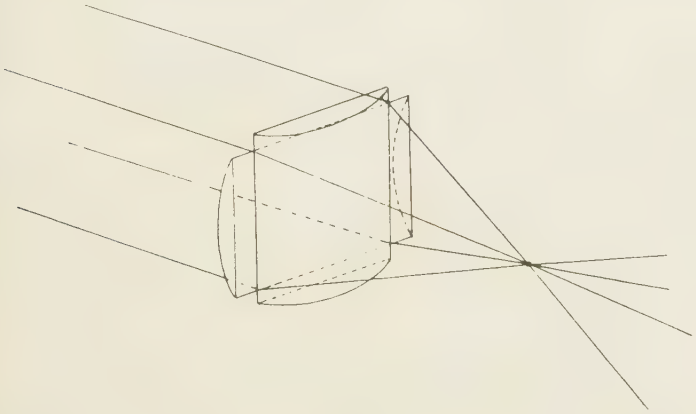


FIG. 28.—CROSSED +CYLINDERS OF EQUAL POWERS FOCUS RAYS AT A POINT.

Neutralization of Lenses.

Any of the comparatively low-power lenses used in ophthalmic work can be neutralized by combining them with lenses of equal but opposite power. For instance, if a + 5 D. lens be held in contact with a − 5 D. lens, the magnifying power of the one is neutralized by the minifying power of the other.

To Ascertain the Nature (+ or −) **of a Lens**, hold the glass about 12 inches in front of the eye and look through it at some distant object (*e.g.*, test-types or window-bars). If on moving the glass through the distance of an inch or so the object looked at appears to move in a direction opposite to the movement of the glass, it is a + glass; while if the object appears to move in the same direction, it is a − glass.

The weaker the lens the quicker the apparent movement, and *vice versâ*. With a plane glass there is no movement at all.

To Ascertain the Strength of a given Lens.— Take a lens of the opposite sign to that of the lens to be tested from the trial-case, and, *holding the two in contact with their centres exactly corresponding*, note the effect produced on looking at some distant object (*e.g.*, test-types, window-bars, etc.) through the combination when in motion.

After trying first one lens and then another, when that is found which exactly neutralizes the effect of the one 'on trial,' so that the object looked at appears stationary during the movement of the combined lenses, the strength of this neutralizing lens (which is known) will give the measure of the strength of the other.

In the case of *a cylinder*, no apparent movement of the object takes place if the lens is moved in a direction *parallel to its own axis;* but movement will take place if the lens is moved in a direction at right angles thereto. Its strength will be ascertained by means of that cylinder of opposite sign which neutralizes its action. To effect this the axes of the two cylinders must be opposite and parallel to each other. For sphero-cylinders, first find the strength of the sphere and then test for the cylinder.

SUMMARY.

Convex lenses are called positive or plus (+) because they converge parallel rays to a real focus.

Concave lenses are called negative or minus (−) because they cause parallel rays to diverge as from a negative or virtual focus.

RULES.

To convert :

Dioptres to metres of focal length, divide 1 by the number of dioptres.
Metres of focal length to dioptres, divide 1 by the number of metres.
Dioptres to centimetres of focal length, divide 100 by the number of dioptres.
Centimetres of focal length to dioptres, divide 100 by the number of centimetres.
Dioptres to inches of focal length, divide 40 by the number of dioptres.
Inches of focal length to dioptres, divide 40 by the number of inches.

POWER AND FOCAL LENGTH.

POWER.	FOCAL LENGTH.	
Dioptres.	Metres.	Inches.
0·25	4·0000	157·48
0·50	2·0000	78·74
0·75	1·3333	52·49
1·00	1·0000	39·37
1·25	·8000	31·50
1·50	·6667	26·24
1·75	·5714	22·50
2·00	·5000	19·68
2·25	·4444	17·50
2·50	·4000	15·75
2·75	·3636	14·32
3·00	·3333	13·12
3·50	·2857	11·25
4·00	·2500	9·84
4·50	·2222	8·75
5·00	·2000	7·87
5·50	·1818	7·16
6·00	·1667	6·56
7·00	·1429	5·62
8·00	·1250	4·92
9·00	·1111	4·37
10·00	·1000	3·94
11·00	·0909	3·58
12·00	·0833	3·28
13·00	·0769	3·03
14·00	·0714	2·81
15·00	·0667	2·63
16·00	·0625	2·46
17·00	·0588	2·32
18·00	·0555	2·19
19·00	·0526	2·07
20·00	·0500	1·97

Reflection.

The change of direction produced when rays of light, striking a surface, are thrown back into the medium whence they came, is termed *reflection* (*re*, back, *flecto*, I bend).

The ray of light falling upon the surface is the *incident ray*, I; it does so at the *point of incidence*, N, and is thrown back as the *reflected ray*, R.

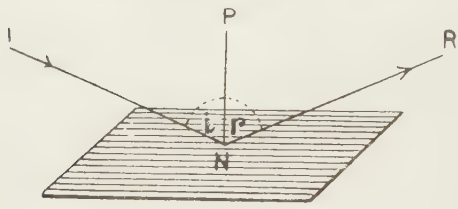


FIG. 29.

The *normal*, P is the line drawn perpendicular to the plane of the reflecting surface at the point of incidence, N.

The reflected and incident rays are on opposite sides of the normal and in the same plane with it.

The angle which the incident ray makes with the normal is *the angle of incidence*, I N P; the angle which the reflected ray makes with the normal is *the angle of reflection*, P N R.

The angle of incidence is equal to the angle of reflection, and is in the same plane with it and the normal.

Mirrors are of two kinds:

1. **Plane.**
2. **Spherical** { (*a*) *concave.* (*b*) *convex.*

1. **Images formed by Plane Mirrors.**—It follows from the law of reflection that the image formed by the ordinary looking-glass, to take an example, appears to be as far behind the mirror as the object is in front of it, and is like the object in all respects except that the right and left parts are interchanged. This is known as *lateral inversion—e.g.*, a man who parts his hair on the left side will see his reflected image with it parted on the right; type set up for printing can be read in a mirror as it would appear printed on the page.

Draw A N and A P to represent two rays incident upon the mirror at N and P, then by the law of reflection these

will be reflected in the direction N O and P Q, and if these latter be produced backwards they will meet each other at *a*.

To an observer placed in front of the mirror anywhere along N O the light would appear to come from *a*, and he would therefore see the image of the point *a* as far behind the mirror as A is in front of it. Since the reflected rays do not actually, but only *appear* to, proceed from *a*, *a* is called a *virtual* image.

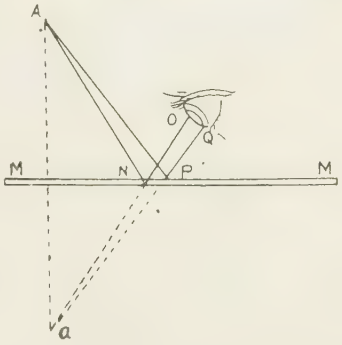


FIG. 30.—VISION IN A MIRROR.

2. **Spherical Mirrors.**—A *spherical* mirror is one whose reflecting surface is a portion of a hollow sphere.

A *concave* spherical mirror is one whose reflecting surface is on the concave side. A *convex* mirror is one whose reflecting surface is on the convex side.

The *centre of curvature* is the geometrical centre of the sphere of which the mirror is a portion, and its *radius of curvature* is the radius of the sphere.

The central point on the surface of the mirror is called the *vertex* or *pole*.

The *principal axis* is the straight line drawn from the centre of curvature to the vertex; straight lines, other than this, drawn through the centre of curvature are *secondary axes*. Any line drawn from the centre of curvature to a point on the reflecting surface is *a normal* at that point.

CONCAVE SPHERICAL MIRRORS.

Rays falling on a concave spherical mirror parallel to the principal axis are brought to a focus on the principal axis at a point F midway between the mirror and its centre of curvature C. This focus *is the principal focus*

FIG. 31.—PRINCIPAL FOCUS OF A CONCAVE MIRROR.

of the mirror, and its distance from the mirror is the *focal length*.

Images formed by Concave Mirrors.—An incident ray proceeding from the centre of curvature C forms a

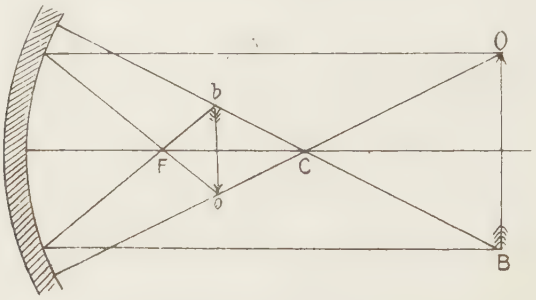


FIG. 32.—FORMATION OF IMAGE BY A CONCAVE MIRROR.

normal with the mirror, and is reflected back along its own course.

An incident ray parallel to the principal axis is reflected back through the principal focus F. An incident ray proceeding from the principal focus is reflected back parallel to the principal axis.

The image of a luminous point will be found at the point where two reflected rays intersect, and it may either be *real* or *virtual*.

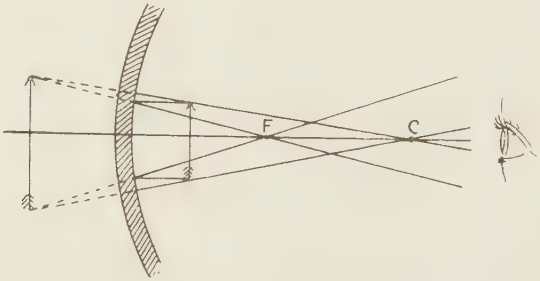


FIG. 33.—VIRTUAL, ENLARGED IMAGE FORMED IN A CONCAVE MIRROR.

By employing the above construction it is seen that *o b* is a real and inverted image of O B, and is diminished in size. Moreover, being a *real* image, the image and the object may be transposed; so that if *o b* be taken as the object, O B will

be its image. This image will be enlarged, and this will always be the case when the object lies between C and F.

If *the object lies between the mirror and its principal focus* the image is *virtual, erect,* and *enlarged,* as is shown in Fig. 33.

SUMMARY OF RESULTS FOR CONCAVE MIRRORS.

Position of Object.	Position of Image.	Characteristics of Image.
At infinity	At F	Real, inverted, decreased.
Beyond C	Between F and C	Real, inverted, decreased.
At C	At C	Real, inverted, equal.
Between C and F	Beyond C	Real, inverted, increased.
Between F and M	Behind M	Virtual, erect, increased.

CONVEX MIRRORS.

As the application of these has but little significance in ophthalmic practice, it suffices to say that the images formed by convex mirrors are always *virtual, erect,* and *decreased in size,* as compared with the object. The geometrical construction follows the rules given above.

CHAPTER II

FORMATION OF THE RETINAL IMAGE

The eye may be likened to a photographic camera, of which the lens is represented by a combination of refracting media, and the sensitive plate by the retina, the focussing for varying distances being effected by a change in the shape of one of the refracting media (viz., the crystalline lens), instead of by an alteration in the length of the optical apparatus.

On passing into the eye, the course of a ray of light is influenced by:

(*a*) The refracting *surface* of the cornea;
The anterior *surface* of the lens;
The posterior *surface* of the lens.

(*b*) The refracting *media*, viz., the cornea, the aqueous humour, the lens, and the vitreous humour.

The data necessary for a knowledge of the formation of the retinal image are:

1. *The radii of curvature of the refractive surfaces*—
   Cornea;
   Anterior surface of lens;
   Posterior surface of lens.

2. *The distance between these surfaces*—
   Anterior surface of cornea to anterior surface of lens;
   Thickness of lens;
   Posterior surface of lens to retina.

3. *The refractive indices of the media*—
   Air;
   Cornea;
   Aqueous;
   Lens;
   Vitreous.

The cornea and the aqueous and vitreous humours are practically all of the same refractive index (1·3365) as compared with air (=1). The lens, whose refractive is 1·4371, may be regarded as suspended in a homogeneous medium of less refractive index compared with itself, but greater compared with the surrounding air.

The course of the rays entering the eye is as follows: On passing from the air through the anterior surface of the cornea, they undergo their greatest deflection, because the difference between the refractive index of the air and the cornea is greater than that between any of the other contiguous media of the eye (*vide* p. 30). From a condition of parallelism the rays are brought to one of such convergence, that if continued they would come to a focus 10 mm. behind the retina (in air), and on meeting the lens, they undergo such further convergence that if prolonged in direction they would be brought to a focus 6·5 mm. behind the retina (in air). Leaving the posterior surface of the lens, the rays next enter the vitreous humour (a medium of less refractive index), and undergoing their final refraction, are ultimately brought to a focus upon the layer of rods and cones.

The rays of light, then, in passing through the eye, are subjected to the influence of various media with different radii of curvature and different indices of refraction, and, to simplify the working out of the problem connected with the formation of the image, these various media have been reduced to their simple optical equivalent. Calculations made on this basis give results with regard to the construction and magnitude of the retinal image which may be taken as approximately identical with those obtaining in the natural eye.

In order to simplify the problem, we shall begin by tracing the rays of light through a simple lens-system on the basis of the *cardinal points* method as laid down by Gauss (*vide* p. 13).

The Determination of the Path of Rays through a Simple Lens-System.

X X = principal axis—the straight line passing through centre of curvature of both surfaces. Rays pass along it undeviated.

H_1 H_2=*first and second 'principal points.'* A ray which is directed to H_1 will pass through to H_2 in a direction parallel to the principal axis.

F_1=*first focal point;* F_2=*second focal point.* Rays passing

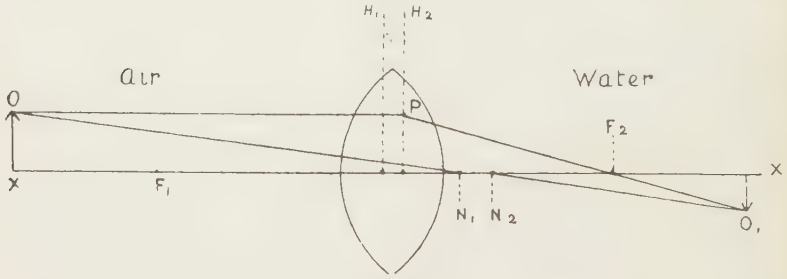


FIG. 34.

through the lens parallel to the principal axis will be brought to a point at one of these foci according to its direction—*e.g.*, X X and O P will meet at F_2.

N_1 N_2=*first and second nodal points.* If the lens be surrounded by air, these are the same as the principal points; but if there be air in front and water behind, as in the case of the eye, the principal points become *displaced backwards towards the denser medium*—that is, from H_1 H_2 to N_1 N_2—and their property thus transferred to the nodal points.

A ray which in the first medium is directed to the first nodal point N_1 will pass, after refraction, through and from the second nodal point N_2 in a direction parallel to its first direction. *All such rays are secondary axes.*

Working on the basis of the cardinal points method of Gauss, Helmholtz and others have constructed as a substitute for the dioptric system of the human eye a hypothetical *schematic*, or *diagrammatic*, eye, having an antero-posterior measurement of approximately 23 mm. (see below).

The values given by Helmholtz for this schematic eye are as follows:

1. *The Radii of Curvature of the Refractive Surfaces.*

Cornea - - - - -	= 7·829 mm.
Anterior surface of lens - - -	= 10·0 „
Posterior surface of lens - - -	= 6·0 „

2. *The Distances between these Surfaces.*

Anterior surface of cornea to anterior surface of lens	= 3·6 mm.
Thickness of lens	= 3·6 „
Posterior surface of lens to retina	= 15·619 „
Anterior surface of cornea to retina (yellow spot)	= 22·819 „

3. *Indices of Refraction.*

Air	= 1·0
Cornea, Aqueous, Vitreous	= 1·3365
Lens	= 1·4371

In this schematic eye, which may be taken to represent the average healthy eye, by accepting the values as given in

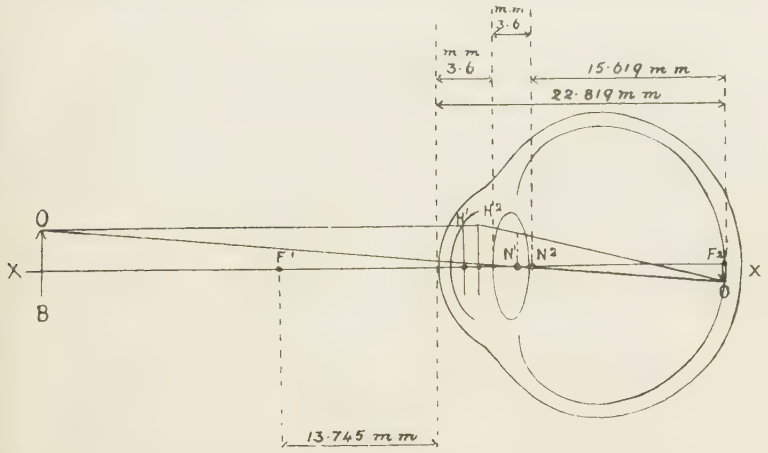


FIG. 35.—DIAGRAM OF A HORIZONTAL SECTION OF THE SCHEMATIC EYE SHOWING POSITION OF CARDINAL POINTS.

X X, optic axis ; F_1 F_2, anterior and posterior focal points ; H^1 H^2, first and second principal planes ; N^1 N^2, first and second nodal points. The intersection of the lines O H ^2o and O N_1 N_2 o gives the image of the point O of the object O B. O o is a *secondary axis*.

these tables, and assuming the centres of curvature of the different media to be situated on the optic axis, the position of the cardinal points corresponding to those of ordinary lenses have been calculated by Helmholtz as follows :

The first focal point = 13·745 mm. in front of anterior surface of cornea.

The second focal point = 15·619 mm. behind posterior surface of lens.

The first principal point = 1·753 mm. behind the cornea.

The second principal point = 2·106 mm. behind the cornea.

The first nodal point = 6·968 mm. behind the vertex of the cornea.

The second nodal point = 7·321 mm. behind the vertex of cornea.

The position of the second focal point, which corresponds to the situation of the retina, is 22·819 mm. behind the anterior surface of the cornea, and for the sake of simplicity is usually said to be 23 mm. (If the thickness of the choroid and sclerotic were added, it would measure about 24 mm.)

The Reduced Eye of Listing.

For purposes of demonstration the optical problem may be still further simplified by *reducing* the natural media of the eye to a single homogeneous medium of known refractive index and known radius of curvature, bounded by

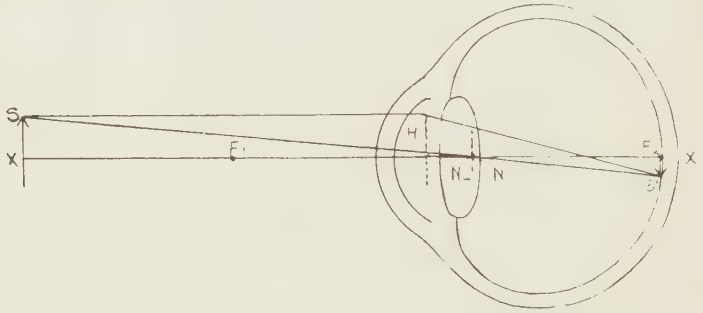


FIG. 36.—THE REDUCED EYE OF LISTING, SHOWING THE FORMATION OF THE IMAGE.

During accommodation the nodal point N becomes advanced to N_2, the size of the image being thereby increased.

air in front and water behind to represent the aqueous and vitreous humours.

In *this reduced eye of Listing* the distance between the two

principal points and that between the two nodal points is so minute (0·4 mm.) that for all practical purposes we may regard them *as merged into one principal point* H, *and one nodal point* N, which latter will represent the optical centre of the single refracting medium. The nodal point is of particular importance in calculating the size of the retinal image, inasmuch as all straight lines which proceed from different points of an object to corresponding points of its image intersect at that point. If straight lines (such as S S_1) be drawn from each point of the object S X through the *nodal point* N they will pass on unrefracted, each of such straight lines being *a secondary axis*.

The retinal image is accordingly inverted, and will be composed of a collection of images of the points of the object, each focal point on the retina being conjugate with the corresponding point of the object.

The values of the *reduced eye of Listing* are as follows :

Radius of curvature of the single refracting surface -	= 5·215 mm.
Index of refraction of the single refracting medium - (which is the same as that of the vitreous humour).	= 1·3365 „
Distance of the nodal point from the anterior surface -	= 5·0 „
„ „ Posterior focal point - - -	= 20·713 „
„ „ Anterior focal point - - -	= 15·498 „

Rays coming from the anterior focal point become parallel to the optic axis after refraction.

Rays parallel to the optic axis before refraction meet at the posterior focal point.

By this reduction the construction of the image and the various calculations with respect to its magnitude may be made with greater ease.

Definitions.

Static refraction : This term has reference to the refraction of the eye *at rest*, and is used in contra-distinction to

Dynamic refraction, or the increased refraction which is the result of the exercise of the accommodation.

Emmetropia is the term introduced by Donders to express that standard condition of sight in which the retina, E, is situated at the posterior focal point, F_2, of the refractive media; it is characterized by the fact that, with accommodation *physiologically* relaxed, parallel rays are focussed on the retina. The antero-posterior axis, measured from the vertex of the cornea to the yellow-spot, is approximately 23 mm. Departures from this standard, termed generically *ametropia*, may be in respect of either—

Hypermetropia, in which the retina, H, is *in front* of the posterior focal point, F_2, so that parallel rays are focussed *behind* the retina, the antero-posterior axis being too short —that is, less than 23 mm.; or

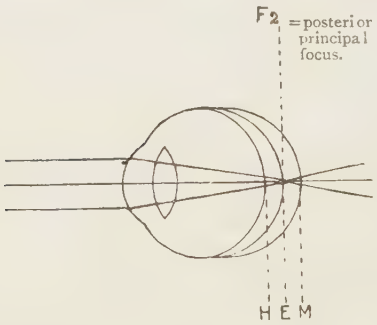


FIG. 37.

Myopia, in which the retina, M, is *behind* the posterior focal point, F_2, so that parallel rays are focussed *in front* of the retina, the antero-posterior axis being too long — that is, more than 23 mm.

The Optic Axis is the geometrical axis around which the eye is symmetrical as a whole. It passes through the centre of the cornea, and meets the posterior pole, as a rule, at a point between the yellow-spot and the optic disc. (*The yellow-spot, then, is excentric to the optic axis.*) On it are situated the six cardinal points. When it passes through the macula it is the *line of vision* as well.

The Line of Vision is the straight line drawn from the

point 'fixed'* (*i.e.*, the centre of the object looked at) to the centre of the yellow-spot (*i.e.*, to the centre of the image of the object). If the eye media formed a properly centred system, as is the case with optical instruments, this line would coincide with the optic axis; instead of this, however, it usually cuts the optic axis at the nodal point of Listing, and in emmetropia intersects the cornea *to the nasal side* of the axis. For infinity the *visual lines* are parallel. (As Maddox puts it: 'We do not see straight out of our eyes but obliquely out of them,' owing to the fovea centralis being excentric to the optic axis.)

In emmetropia the optic axes diverge about 5° from the visual lines.

In hypermetropia the optic axes diverge more than 5°.

In myopia the optic axes diverge less than 5° and may even converge.

This explains how it is that in certain cases of hypermetropia there may be an *apparent* divergent squint, and in myopia an *apparent* convergent squint.

The Centre of Rotation, R (Fig. 38), is the almost immovable point on the optic axis on which the eyeball rotates as a centre. (To be precise, the globe can translate from 1 to 2 mm.)

The Line of Fixation, O R, is the line uniting the object, O, with the centre of rotation, R. Although not strictly the same as the *line of vision*, O N_1 N_2 *y s*, yet the two fall so nearly together that, for all practical purposes, they may be regarded as one.

Angle Alpha and Angle Gamma (Fig. 38).

The cornea being a segment of an ellipsoid, and not the segment of a sphere, its vertex, V (anterior extremity of major axis), and its centre, C, do not exactly correspond (a condition to some extent neutralized for 'seeing' by the pupillary area of the cornea being approximately spherical), and in consequence the major axis V L does not correspond to the optic axis X C X_1, but cuts it (at *a*).

* *By the term 'fixing' is understood that adjustment of the eye by means of which the yellow-spot is brought into alignment with an object so that the image falls exactly on it.*

Angle Alpha (α), O *a* V, is the angle included at the intersection of the major axis of the corneal ellipsoid with the visual line O N_1 N_2 *y s*. It may be outside the line of vision when it is called *positive* (+); inside, when it is called *negative* (−); or, if the major axis coincides with the optic axis, it is *nil* (0).

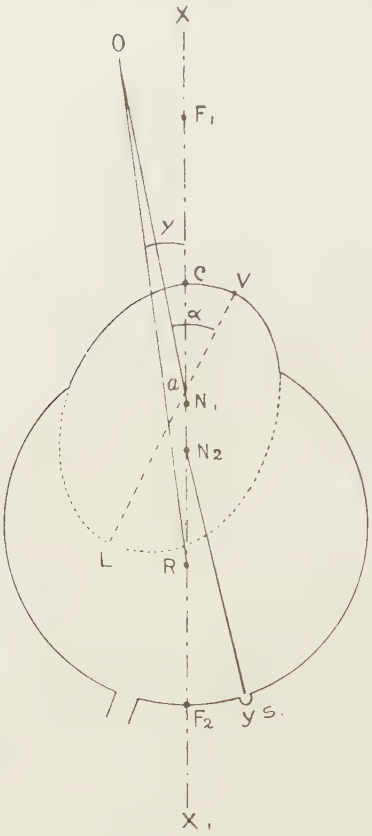


FIG. 38.—RIGHT EYE.

This figure, which is very diagrammatic in order that the angles α and γ may be rendered more apparent, is taken from Landolt. X X_1 is the optic axis; F_1 and F_2 are the anterior and posterior focal points; N_1 N_2, first and second nodal points; R, centre of rotation of eyeball; C, centre of cornea; V L, major axis of the corneal ellipsoid; *ys*, yellow spot; O, point of fixation; O N_1 N_2 *ys*, line of vision; O R, line of fixation; O *a* V, angle alpha; O R X, angle gamma.

Angle Gamma (γ), O R X is the angle included at the intersection of the optic axis with the line of fixation, and

its size accordingly represents the degree of excentricity of the yellow-spot. Like the angle alpha, it may be either +, −, or 0. It is of importance in estimating the amount of squint.

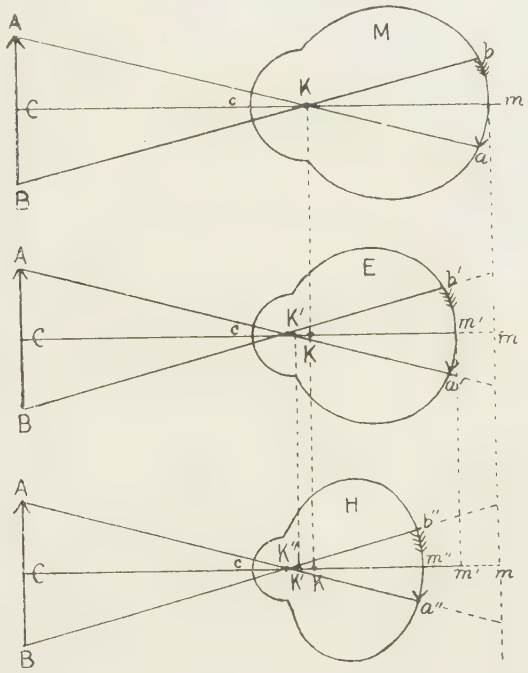


FIG. 39.

These diagrams are modified from Landolt, and illustrate the differences in the size of the retinal images in *myopia*, M, *emmetropia*, E, and *hypermetropia*, H. The static refraction of all is assumed to be the same. Each eye fixes an object, A B, lying at the finite distance, C *c*, the image being accurately focussed on the respective retinæ. While the eye is in a state of rest the nodal point, K, occupies the same position in all three.

If in M the far-point corresponds to C, K undergoes no translation, and the retinal image has the size *a b*.

In E accommodation is necessary to focus at the finite distance C, so the nodal point translates from K to K′ (the increase of the refraction due to accommodation being represented by increased convexity of the cornea). Notwithstanding the advancement of the nodal point, the image *a′ b′* is smaller than *a b*, because K′ *m′* is less than K *m*.

In H a still greater effort of accommodation is necessary (represented by increased curvature of the cornea), and K translates to K″.

The image *a″ b″* is less than *a′ b′*, because K″ *m″* is less than K′ *m′*.

It follows that the greater the hypermetropia, the smaller must be the retinal images.

Visual Acuteness.

Definitions.—*Light sense* is the power of appreciating intensity of illumination.

Form sense is the power of appreciating the shape or external configuration of an object.

Colour sense is the power of appreciating the different wave-lengths concerned in the phenomena of colour.

The Visual angle, o N *b*, is the angle included between the straight lines drawn from the boundaries of the object looked at, O B, *through the nodal point*, N, to the boundaries of the image, *b o*, formed on the retina. If F_2 represents the position of the posterior focal point, then the value of the distance N F_2 is an important datum in calculating the size of the retinal image, because the angle is always situated at the nodal point, and the size of the retinal image varies with the value of N F_2. From this it can be understood that, inasmuch as the nodal point is practically *always in the same place in all kinds of eyes*, in hypermetropia the retinal image is smaller and in myopia larger as compared with that image in emmetropia; for in the one case the distance (N F_2) is less, and in the other case greater, than it is in emmetropia (*vide* Fig. 39).

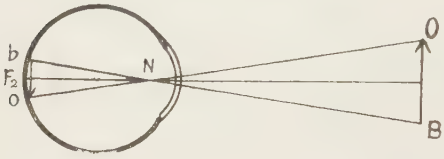


FIG. 40.—VISUAL ANGLE=*o* N *b*.

The size of the visual angle is in direct proportion to the magnitude of the object, but in inverse proportion to its distance.

By *visual acuteness* is meant the smallest visual angle at which the eye can recognise the *form*, or external configuration, of an object. In this definition it is assumed that if the refraction of the eye be abnormal such abnormality has been corrected by glasses.

According to the classical results obtained by Helmholtz, the smallest visual angle under which two points can be separately distinguished is one subtending 50 seconds of arc (called for simplicity 1 minute), and corresponding to a

retinal image of about ·004 mm., which is approximately the diameter of one of the foveal cones.

As the result of measurements made on a large number of healthy eyes at all ages, it has been established *that an object, in order to be seen with clear definition as a whole, must subtend a minimum visual angle of approximately* 5 *minutes.*

VISION-TESTING.

Visual acuteness (V. or V. A.) is tested by the power of distinguishing letters inscribed within squares and placed 6 metres (20 feet) off, because at this distance the rays of light of the different pencils will enter the eye practically *parallel*. It is expressed by the formula $V = \frac{d}{D}$, where the numerator d indicates the distance at which the letters in question subtend a visual angle of 5 minutes, and the denominator D the farthest distance at which the letters can be read. Thus $V = \frac{6}{6}$ means that letters which subtend a visual angle of 5 minutes at 6 metres can be read at a distance of 6 metres.

Snellen's test-types are those in common use for determining the acuteness of vision. The principle involved in their construction is that, *for a particular distance*, each individual letter of the type subtends a visual angle of 5 minutes—a standard of magnitude which, as previously stated, has been accepted as the minimum for normal acuteness of vision with reference to an object as a whole, whilst each component part of the object must subtend a minimal visual angle of 1 minute.

Each separate letter is inscribed within a square which in its entirety subtends an angle of 5 minutes at its appropriate distance, and is subdivided into twenty-five smaller squares, subtending visual angles of 1 minute. Each component part of the letter fills the entire space of one of the small squares, and so subtends a visual angle of 1 minute.

FIG. 41.

The test-type itself consists of letters arranged in successive rows, the letters of each row being smaller than those of the row immediately above. This

diminution in size proceeds in a definite ratio from the top to the bottom (*vide* Fig. 42).

Black letters on a cream-coloured background (to lessen irradiation) are the most satisfactory, and the precise distance at which each row should be read is indicated by Roman numerals of small and inconspicuous type.

Each letter in the

1st	row	subtends	a	visual	angle	of 5′	at 60 metres' distance.
2nd	,,	,,	,,	,,	36	,,	,,
3rd	,,	,,	,,	,,	24	,,	,,
4th	,,	,,	,,	,,	18	,,	,,
5th	,,	,,	,,	,,	12	,,	,,
6th	,,	,,	,,	,,	9	,,	,,
7th	,,	,,	,,	,,	6	,,	,,

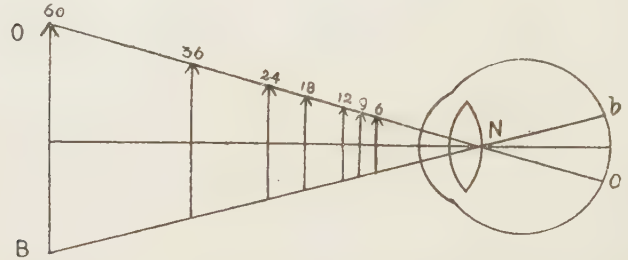


FIG. 42.—DIAGRAM TO SHOW THAT IF THE SIZE OF THE OBJECT INCREASES IN EXACT PROPORTION WITH ITS DISTANCE IT WILL BE SEEN UNDER THE SAME VISUAL ANGLE, *o* N *b*.

The numbers refer to the distances in metres.

Application.—If a patient can read the letters in the lowest row 6 metres off, he will be able to read the letters in all the other rows at their appropriate distances.

The Method of Procedure for Testing Vision.—The patient is placed during examination at a distance of 6 metres from the test-types.

Each eye must be tested separately, the one not under examination being excluded. If the lowest line can be read, we denote the condition as $V=\frac{6}{6}$; if only the sixth line, as $V=\frac{6}{9}$; if the fifth, as $V=\frac{6}{12}$, and so on.

What do these fractions signify? The numerator, let it be repeated, represents the distance of the patient from the type,

the denominator the distance at which, with normal vision, the letters can be read. Thus, V = $\frac{6}{18}$ means that at a distance of 6 metres, only those letters can be read which ought to be read at a distance of 18 metres—*i.e.*, V is $\frac{6}{18}$.

Again, V = $\frac{6}{60}$ means that a patient standing 6 metres off can only read those letters which he ought to be able to read 60 metres off, a fact which implies that he requires them to subtend a much greater visual angle (which would give greater retinal stimulation) in order to be able to see them clearly. If the patient cannot read even the highest row at 6 metres' distance, he should be placed 1 metre nearer to the type, and if he is still unable to read it, he should be brought nearer by successive stages of 1 metre until he reaches the spot at which it can be seen clearly. Now, according to his ability to read the topmost letter at 5, 4, 3, 2, or 1 metre, we denote this visual acuteness by the fractions $\frac{5}{60}$, $\frac{4}{60}$, $\frac{3}{60}$, $\frac{2}{60}$, or $\frac{1}{60}$.

By the formula V = $\frac{1}{60}$ the fact will be denoted that the letter which ought to be read at a distance of 60 metres can be made out no further off than at a distance of 1 metre.

If the topmost letter cannot be read even at 1 metre—that is, V = less than $\frac{1}{60}$, we next ascertain how far off the patient can count the outstretched fingers of the examiner held up at varying distances against a dark background. If he should be quite unable to do this, his ability to discern the *movement* of a hand passed backwards and forwards in front of his face should be tested.

Finally, if 'hand movement' also should give no result, examination by means of a lamp and mirror must be employed to find out whether bare *Perception of Light* (P.L.)—that is, the power of distinguishing between light and darkness—be present.

Thus, the degrees of visual acuteness, as represented by formulæ, would be the gradations between the extremes V = $\frac{6}{6}$ and P.L.

Now, if a patient can read $\frac{6}{6}$, is his vision necessarily normal? No; for he may be hypermetropic and 'accommodating.' The fact that his vision is $\frac{6}{6}$ merely excludes myopia and astigmatism.

In dealing with the subject of visual acuteness it is to be understood that we are concerned solely with *central* or *yellow-spot* vision, as it is only the images which are thrown upon this particular region of the retina, the *region of maximum sensitiveness*, that can be clearly perceived, the yellow-spot alone being sufficiently sensitive, for example, for the purpose of reading.

Images formed on peripheral parts of the retina are only indistinctly recognised, in conformity with the principle that retinal sensitiveness decreases progressively from a maximum at the yellow spot to a minimum at the periphery, the extreme zone of the latter being about 250 times less sensitive than the fovea centralis itself.

Since the size of the retinal image varies as the distance of the nodal point from the retina, the nodal point being practically always in the same position, it follows that if the retina be too far forward, as in hypermetropia, the image will be smaller; whereas if the retina be too far back, as in myopia, the image will be larger (see Fig. 39).

The nodal point is displaced forwards by convex glasses and backwards by concave glasses, so that the retinal image will be enlarged in the former case and diminished in the latter. (This statement has reference to the position at which the glasses are usually worn—that is, in front of the *first focal point* of the eye.)

CHAPTER III

ACCOMMODATION AND CONVERGENCE

Accommodation.

In the passive or resting state (static refraction), the emmetropic eye is focussed (F_2) for the parallel rays ($p\ p$) coming from an object at *infinity* (*i.e.*, 20 feet and beyond). From an object nearer than 20 feet (d) the rays enter the eye divergently, and, since it is not furnished with any contrivance for altering its *length*, if the refractive media were rigid, clear and distinct vision would be possible for distant objects only, for the divergent rays coming from a near object (d) would be brought to a focus behind the retina (at d_1). The healthy eye, however, is capable of seeing accurately both near and distant objects, and the function by means of which it can thus adapt its focus for varying distances is termed *accommodation*, which brings into play the *dynamic refraction*.

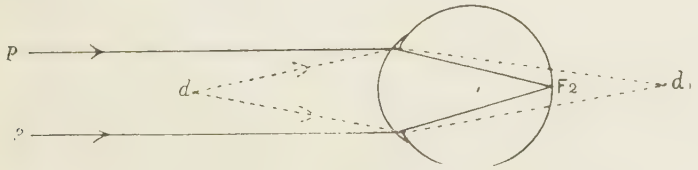


FIG. 43.—THE EMMETROPIC EYE.

In a state of rest parallel rays, $p\ p$, are focussed at F_2 (the posterior principal focus), and divergent rays coming from d are focussed at d_1. The function of accommodation is to advance d_1 to F_2.

Mechanism of Accommodation.—The particular medium in the eye concerned in the act of accommodation

is *the crystalline lens*, a stationary biconvex body placed behind the iris, having its anterior pole on the same plane as that of the pupil. It is not rigid, but semi-fluid and elastic, its elasticity being such that, in obedience to certain influences, *it tends to approximate to the shape of a sphere*, the radius of curvature of the anterior surface of which is capable of change from the length of 10 mm. in static refraction to the length of 6 mm. in extreme dynamic refraction, and that of the posterior surface from 6 mm. to 5·5 mm., *its position meanwhile remaining fixed and unalterable.*

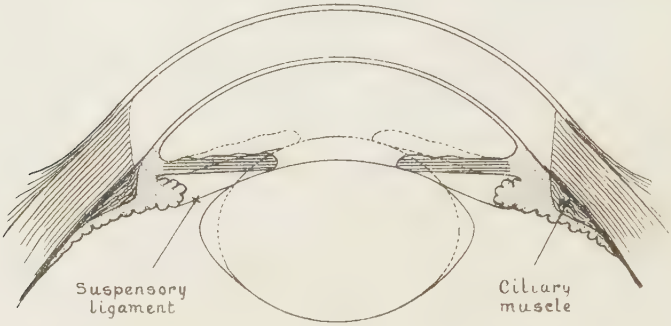


FIG. 44.

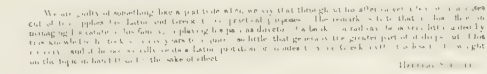
Whilst in a state of rest, the front surface of this elastic lens is kept compressed by a transparent membrane, the *suspensory ligament*, which at its periphery is attached to the *inner* side of the ciliary processes. The *ciliary muscle* has its fixed point at the corneo-scleral junction, and is inserted into the *outer* side of the ciliary processes. By its contraction, the processes are advanced, and the tension of the suspensory ligament thereby relaxed, thus allowing the hitherto compressed anterior surface of the elastic lens to spring or bulge forwards. Its tissue being *incompressible as a whole*, the lens can only alter *in shape*, and not in volume. During accommodation the lens becomes more globular, the pupillary margin of the iris advances, the pupil contracts, and the anterior chamber becomes shallower.

The choroid and retina both move slightly forward during accommodation, and so become somewhat stretched—*a fact of special importance in connection with the treatment of disease in these tunics* as indicating *rest*

by the instillation of atropine, etc., and the avoidance of efforts of accommodation.

The effect of accommodation is that of introducing an additional convex lens within the eye, and the amount of extra refracting power which is thus obtained will vary with the distance of the object from the eye—*i.e.*, with the degree of divergence of the entering rays.

Punctum Proximum (*p p*), or **Near-Point.**—The nearest point at which an object of a given size can be seen with clear definition is the *near-point* (*p p*). Its exact position is found by bringing the 'print' (No. 1 Jaeger) close to the eye, and measuring the shortest distance at which the words can be clearly and distinctly read by the exercise of the greatest possible accommodative effort.



NO. 1 JAEGER.

Another method is by the *wire-optometer*. The patient, with one eye excluded, holds the instrument in his hand, and raises it against a white background (*e.g.*, sheet of paper). The optometer is then approximated to the open eye until the closest position is reached at which the wires can be seen with sharp, unblurred definition. If the distance between the instrument and the outer canthus be now noted, the number of dioptres of accommodation exerted can be read off on the steel tape.

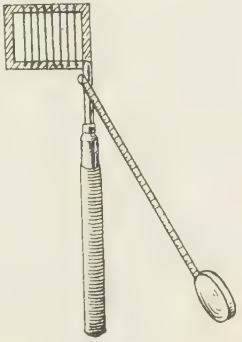


FIG. 45.—WIRE OPTOMETER WITH TAPE-MEASURE.

Punctum Remotum (*p r*), or **Far-Point.**—When accommodation is completely relaxed, the eye is adapted for its *far-point* (*p r*).

To recapitulate: The term (1) *static* refraction refers to the refraction of the eye *at rest*, accommodation being in abeyance; the term (2) *dynamic* refraction refers to the *plus* or *extra refraction* brought about by the employment of accommodation; while the term (3) *total* refraction denotes the sum of (1)+(2).

Amplitude of Accommodation is the measure of the full accommodative power exerted in order to adjust the eye from its far-point to its near-point, and represents the maximum dynamic effort of which the eye is capable. It corresponds to a glass of that power which, if placed in front of the eye at rest, would be equivalent to this additional refractive power of the crystalline lens. [This statement assumes that the glass is placed in the *anterior focal plane* of the eye (*q.v.*, p. 31).]

Range of Accommodation denotes the distance, or interval of space, between the *far* and *near* points.

Relative Accommodation. — The functions of accommodation and convergence are closely associated, the exercise of a certain definite amount of accommodation implying the exercise of a certain definite amount of convergence under ordinary circumstances; but the two functions can be dissociated, as is proved by the following facts:

(i.) If a near object be fixed and a *concave* or *convex* glass be placed before the eyes, it is found that the object can still be distinctly seen, proving that accommodation must be altered, whilst convergence remains the same.

(ii.) If a prism with its base inwards be placed in front of one eye, the fixed object can still be seen as a single one, proving that the convergence has been altered whilst the accommodation remains the same.

(iii.) Hypermetropes require to accommodate for distance, but not to converge.

(iv.) Myopes require to converge for their far-point, but not to accommodate.

(v.) Atropine paralyzes accommodation, but leaves convergence unaffected.

The strongest glass, whether convex or concave, with which the object can be clearly seen, *convergence remaining the same*, denotes the measure of the *relative accommodation*.

Amplitude of Accommodation.

At ten years of age the normal child possesses the maximum dynamic refraction of its lifetime, which = 14 D. of accommodation.

Since a 1 D. lens has a focal length of 1 metre or 40 inches (actually 39·37 inches), ∴ +14 D. represents a lens of focal length =

$$\frac{1 \text{ metre} = 100 \text{ cm.} = 40 \text{ inches}}{14} = 3 \text{ inches (about).}$$

Thus, the normal child at ten years of age, by exerting his maximum dynamic refraction, has *a near-point of 3 inches.*

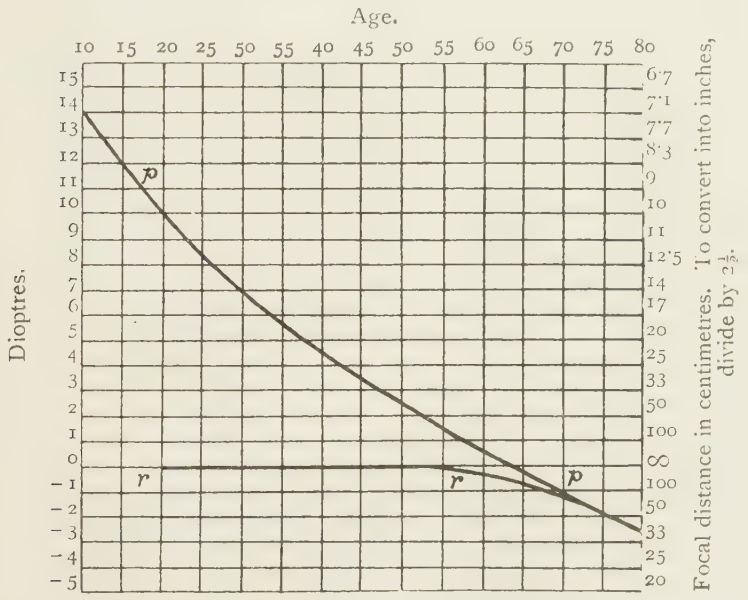


FIG. 46.

From this age the amplitude of accommodation progressively diminishes at the same rate in all eyes up to the age of about seventy, by which time it is, as a rule, entirely lost, and the near-point (*pp*) recedes *pari passu* with it. The progressive diminution is owing to loss of elasticity, the result of a gradual hardening process taking place in the lens-substance,

in consequence of which it becomes less and less capable of changing its form and curvature.

This decline in accommodation can be represented diagrammatically in the form of a curve, as shown in the table (Fig. 47) taken from Donders. The line *r r* represents the position of the far-point, and the line *p p* that of the near-point.

The ciliary muscle, like other muscles, is liable to fatigue, especially when contracted to its fullest extent. As a matter of fact, the maximum contraction can only be maintained for a very brief period, and hence an object cannot be 'fixed' for any length of time if it is at the position of the *punctum proximum*. With most persons only about two-thirds of the accommodation can be used for sustained vision, the remainder being held in reserve.

Accommodation increases the Size of the Retinal Image.—It has been stated that the visual angle is situated at the nodal point. As a result of accommodation, the nodal point is advanced towards the cornea from N to N_1, as shown in the diagram; *i.e.*, the visual angle increases. Hence the optical effect of accommodation is slightly to increase the size of the retinal image.

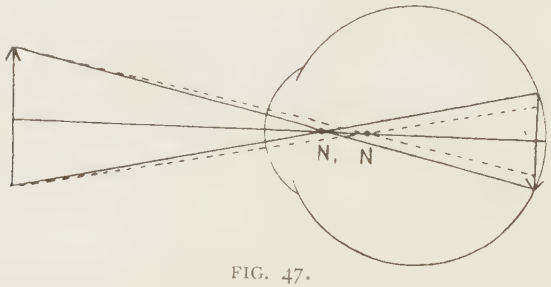


FIG. 47.

Diagram of the 'reduced eye,' showing how accommodation increases the size of the retinal image by advancing the nodal point from N to N_1. The dotted lines indicate the size of the image during non-accommodation.

Spasm of the Ciliary Muscle.—This is a condition in which the ciliary muscle is unable to relax properly in consequence of excessive use of the accommodation. The spasm may cause a myopic eye to become more myopic; an emmetropic eye myopic; a hypermetropic eye less hypermetropic, or even myopic. *It is observed, as a rule, in young subjects only, disappearing as age advances.* It may occur in connection both with hypermetropia and myopia. The spasm readily yields to the instillation of atropine, but is liable to recur after its use is discontinued. Drugs which contract the pupil, such as eserine, also contract the ciliary muscle.

CONVERGENCE.

When one eye 'fixes' an object, it is directed to it in such a way that an image of the object is formed on its yellow spot, the line joining the centre of the object with the centre of the image being known as the *visual axis*.

When an object is 'fixed' with the two eyes simultaneously, both visual axes are directed to it, so that an image is formed exactly on each yellow-spot. These two images are psychologically blended into one image, and this constitutes *binocular single vision*.

It is absolutely necessary, for binocular single vision, that the object looked at *should be focussed on each yellow spot*, otherwise *double vision* must result.

When the object is situated at infinity (20 feet and beyond), the visual axes of the two eyes may be regarded, for all practical purposes, as parallel.

When the object is situated at a finite distance (less than 20 feet), *convergence* of the eyes is necessary in order to bring the two yellow-spots to bear upon the object looked at; this is effected by the simultaneous contraction of the two internal recti.

Measurement of Convergence—the Metre-Angle.—The *metre-angle* MA. is taken as the standard unit.

For infinity (20 feet and over) the lines of fixation E I, and E′ I′ (Fig. 48) may be regarded as parallel.

For distances less than infinity it is necessary, in order that the images may be received on the yellow spots, that the lines of fixation be brought to bear on the object looked at.

The angle which the 'line of fixation' makes with the 'perpendicular' drawn from the middle of the base line E E′ is the *angle of convergence—e.g.*, the angles E C B, E D B, and E F B (Fig. 48).

The unit MA. (*metre-angle*) is the angle formed by the line of fixation at a point on the median plane C at a distance of 1 metre from either eye. Thus E C B is the MA.

It is taken as the standard unit for measuring degrees of convergence.

If an object be situated $\frac{1}{2}$ metre from the eye (at D), the degree of convergence necessary for binocular vision will be 2 metre-angles (2 MA.); if $\frac{1}{3}$ metre (at F), 3 metre-angles (3 MA.), and so on.

Assuming the object to be placed 2 metres off, then for binocular vision the size of the angle is $\frac{1}{2}$ MA.; 4 metres off, $\frac{1}{4}$ MA., and so on.

When the visual lines are directed to infinity, and so parallel, the metre-angle is zero.

Under ordinary circumstances accommodation and convergence act in concert.

In the case of a young emmetrope, the number of dioptres

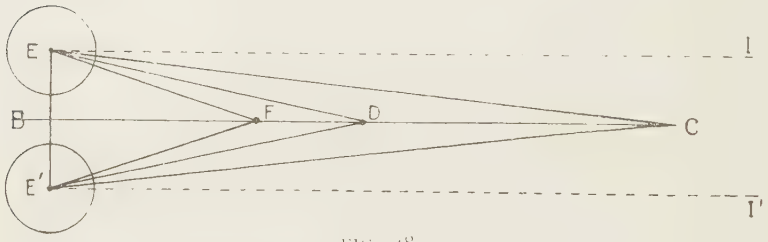


FIG. 48.

E E′ = centre of rotation of the two eyes.
E B E′ = base line. From middle of base line draw the median plane, B C, which is at right angles to base line.
E C and E′ C = visual axes, or lines of fixation, converging to object, C, situated on median plane, and 1 metre distant from base line.
E I and E I′ = visual axes directed to infinity.

of accommodation employed corresponds strictly to the metre-angle of convergence—*e.g.*, looking at an object 1 metre off implies +1 D.AC., 1 MA. of convergence; $\frac{1}{2}$ metre off, +2 D.AC., 2 MA. of convergence; $\frac{1}{3}$ metre off, +3 D.AC., 3 MA. of convergence.

To Test the Power of Convergence.—Place two prisms, with their bases outwards, in front of the eyes; the strongest pair which when looked through at a distant object does not cause double vision is the measure of the power of convergence.

The power of convergence does not diminish regularly

with advancing years like that of accommodation, but is retained throughout life in conformity with the retention of general muscular vigour.

As previously stated, convergence and accommodation are associated functions, and not only can dissociation between the two functions often occur, but it also frequently must, as we shall see in dealing with hypermetropia and myopia, because a hypermetrope of, say, +2 D., looking at an object ½ metre off, must accommodate to the extent of 4 D. (inasmuch as he uses +2 D. to render himself emmetropic), whereas he would only employ 2 metre-angles of convergence. Likewise a myope of −2 D. would not require to accommodate at all when looking at an object ½ metre off, whereas he would have to converge to the extent of 2 metre-angles.

Sometimes the act of convergence cannot be sustained for the usual length of time, and when this happens, the term 'insufficiency of the internal recti,' as first applied by Von Graefe, is used (*vide* chapter on 'Insufficiency').

Field of Vision.

Definitions.—*Vision*, as a generic term, comprises—

Light-sense—i.e., comprehension of the degrees of illumination (ranging from brightness to dulness);

Colour-sense, or comprehension of, and differentiation between, the various wave-lengths concerned in the phenomena of colour; and

Form-sense, the comprehension of the external configuration, shape, or form of a body. This is generally spoken of as 'acuteness of vision' (VA), and in practice is tested as already shown by the ability to distinguish type of a given size. It is denoted by the formula $V=\frac{d}{D}$ (*vide* p. 39 *et seq.*). Visual acuteness is most intense at the yellow-spot, then drops rapidly, and afterwards decreases more or less regularly to the periphery of the retina.

To Test the Light-Sense.—The retina is liable to fatigue, as is evidenced by the fact that if we pass from a brightly-lighted room to a darker one, objects in the latter at first appear obscure and dim. The eyes of a patient must therefore first of all be rested by being kept in darkness for at least fifteen minutes before the test can be applied. At

the end of this time he is requested to read (either 'far' or 'near' type) under bright illumination. Gradually diminishing the degree of illumination, we note the smallest amount of light at which he can decipher the print, and we compare this result with that obtained from one whose light-sense is known to be good; or the procedure may be reversed.

The light-sense varies in different individuals, and need bear no ratio to form-sense. It can be more accurately tested by making use of the 'photometer,' but as the subject has in the present state of our practice little significance, it is not necessary to describe the apparatus.

To Test the Field of Vision—*The Finger Test.*—This is a rough-and-ready method, easy of application, and useful when speedy information is required; also as a preliminary to a more exact test.

The patient, having his back to the light, faces the examiner at a distance of 2 feet. One eye being covered, he is instructed to fix with the other the *opposite* eye of the surgeon, who can thus detect and control any movement on his part. Then, with index-finger extended, the examiner moves his hand upwards, outwards, downwards, and inwards, noting the extreme limit at which in each position the finger can be seen. One advantage of this test is that the patient's field of vision can thereby be compared with that of the surgeon. A small rod, held in the hand and to which is attached a white mark, may be used instead of the finger, or a candle flame may be made to serve the same purpose in a dark room—a method which it is necessary to employ in taking the field of vision of a patient with an opaque cornea, cataract, or other obstruction to vision.

Perimeter Test.—But a far more accurate and exact test, and the one always employed when a careful scrutiny of the field is required, is by the perimeter.

The *perimeter,* in its main essentials, consists of a *quadrant arc,* marked up to 90°, fixed to the upper end of a vertical 'support,' and admitting of rotation through all the meridians. It can be so rotated that it traces out a hemisphere, at the centre of which the eye is placed, the chin meantime being supported on a rest. Attached to the

concave side (which must be black) of the quadrant is the movable *test-object*, white in colour, square in outline (10 mm.), and fixed to a *traveller*, which can be moved along the quadrant. The patient is now to be seated on a chair with his chin on the rest, his head erect, and the eye to be examined (the other being covered) fixing the white disc at the centre of rotation of the quadrant. The 'test-object,' starting from zero, is then moved outwards along the quadrant to the farthest limit at which it can be distinctly seen, this point being marked on a card. The procedure is repeated in the other chief meridians, and recorded in

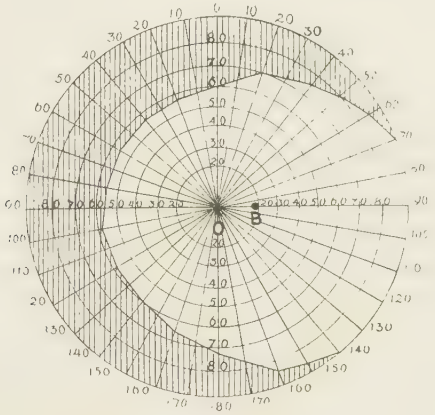


FIG. 49.—PERIMETRIC CHART.

Field of colours in a decreasing scale, thus : white, blue, yellow, red, green.

the same way. The points as registered on the card are now joined together by lines, the result being an irregular figure, which is called a *perimetric chart* of the visual field (Fig. 49).

The chief abnormalities occurring in the field are :

(*a*) *Concentric contraction—i.e.*, insensitiveness of the peripheral zone of the retina, as in *retinitis pigmentosa*, *glaucoma*, *tabes dorsalis*, etc.

(*b*) *Hemiopic contraction—i.e.*, the loss of vision for corresponding halves of the visual fields. If the lesion be between the chiasma and the cortical visual area on the right side,

there will be blindness of the right halves of both retinæ, causing a loss of vision in the left halves of the field; if the lesion destroy the decussating fibres in the chiasma, there

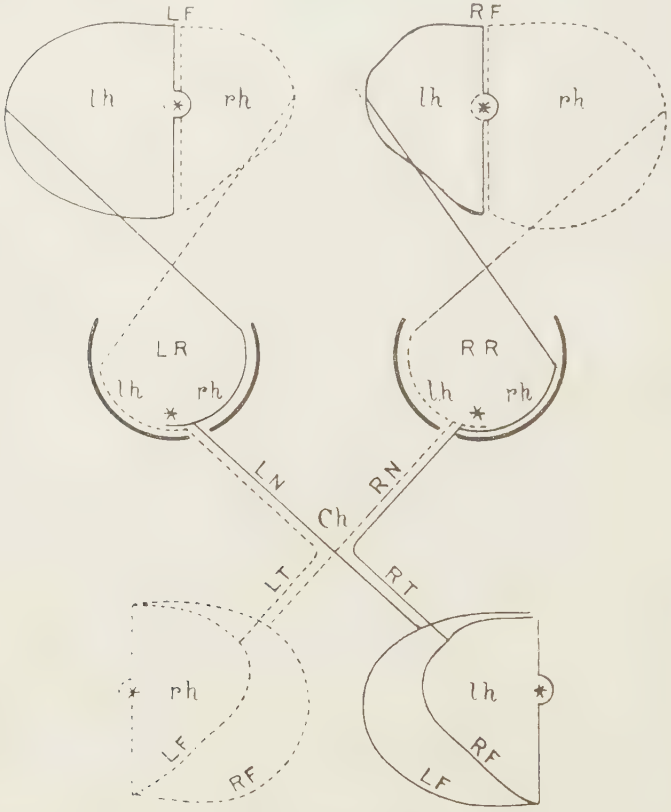


FIG. 50. — DIAGRAM OF THE RELATION OF THE FIELD OF VISION, RETINA, AND OPTIC TRACT ON EACH SIDE. (*Taken, by permission, from Sir William Gowers.*)

R F, L F, right and left fields (the asterisk is at the fixing point); R R, L R, right and left retina (the asterisk is at the yellow spot); *lh*, *rh*, left half and right half of each retina, receiving rays from the opposite half of the field; R N, L N, right and left optic nerves; Ch, chiasma; R T, L T, right and left optic tracts; below, the halves of the fields from which impressions pass by each optic tract are superimposed.

will be blindness of the nasal halves of the retinæ, causing a loss of vision in the temporal halves of the field; if the lesion be on each side of the chiasma, causing an interruption of

the non-decussating fibres, there will be blindness of the temporal halves of the retinæ, causing a loss of vision in the nasal halves of the field.

As a *functional* disorder, hemiopia is common in megrim. It is doubtful if it ever occurs in hysteria, although in the latter affection amblyopia is not infrequent.

Patients with hemiopia are not always conscious of it. Gowers mentions a case in which 'the defect was not discovered until the nurse noticed that the man never ate his potatoes at dinner. They were always put on the same side of his plate, and he never saw them.' Hemiopia may be incomplete, only a segment of each half being lost.

(*c*) Various irregular areas of the retina may be insensitive as the result of *detached retina* or the blocking of branches of the central artery from embolism or thrombosis.

(*d*) There may be certain pathological *blind-spots* (the 'physiological blind-spot' lies 15° internal to the fovea), technically known as *scotomata* ('skotos,' blindness). These scotomata may be either *central*, when they involve the yellow spot, or *peripheral*, when they involve the surrounding retina. When due to actual impairment of the retina, the term *negative* scotoma is employed to express the condition. If in such cases the retina of the affected area is still partially sensitive to light, it is called *relative* scotoma, whereas if the affected area is completely blind the term *absolute* scotoma is used. Negative scotomata are not, as a rule, noticed until the field is examined by the perimeter. They are found in such diseases as choroiditis, retinal hæmorrhages, toxic amblyopias, etc.

On the other hand, the scotomata may be the result of opacities in the cornea, lens, or vitreous, in which case they are termed *positive*, owing to the fact that the patient can 'project' them upon his visual field.

To Test the Field for Colour-Sense.—This is done with the perimeter in precisely the same manner as in testing the field of vision, *coloured discs* being substituted on the 'traveller' to serve as the 'test-object.' Under ordinary circumstances of illumination, the field for colours is smaller than that for white, and it varies for the different colours, which stand in a decreasing scale thus: *blue, yellow, red, green.*

At the extreme periphery, *at ordinary intensities* of illumination, no colours can be recognised, all being seen *as shades of gray;* but if the light be sufficiently intense, the field for colours is as extensive as that for white.

Acquired colour-blindness is sometimes found in such diseases as tabes dorsalis, tobacco amblyopia, etc.

Coloured vision is a very rare disease. It has as its main characteristic that all objects appear of one certain colour, as red, green, blue, or white. The most common kind is *erythropsia*, in which all objects appear of a red colour. It may come on in attacks lasting some hours, or may continue for months. It has been occasionally noticed to occur after removal of a cataract.

At ordinary intensities the central zone alone has proper colour vision. 'There is considerable difference of opinion on the question of the exact limits of the fields for different colours, but there is now fairly general agreement in placing the limits for blue and yellow distinctly outside those for red and green. Nearly all agree that the limits are not fixed, and are greatly influenced by intensity and other factors' (Schafer's 'Physiology').

CHAPTER IV

THE OPHTHALMOSCOPE

Since the parallel rays which enter an eye are brought to a point on the retina by the action of the refractive media, so rays coming from a point on the retina, being acted on by the same media, must emerge parallel; for it is an optical principle that any illuminated point may be considered to act as a source of illumination from which light radiates in all directions.

This, of course, refers to emmetropia; for in *hypermetropia* the rays will emerge *divergent*, and in *myopia convergent* (*vide* p. 66).

If the emergent rays could be received into another eye, an image would be seen of the spot on the retina whence they came. Moreover, if the emergent rays are made to pass through a convex-lens, an image of the illuminated spot on the retina is formed at the distance of the principal focus of the lens in question.

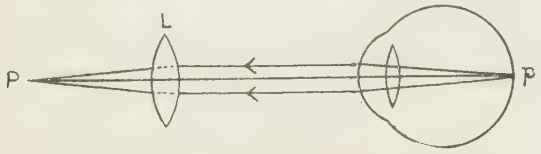


FIG. 51.—EMMETROPIC EYE.

p, an illuminated point on the retina; P, an image of p formed at the focus of the lens L.

The structures within the eye are not self-luminous, and, in order that the interior may be rendered visible, three conditions must be fulfilled:

1. The eye to be examined must be illuminated.

2. The observer's eye must be in a position to receive the rays which emerge from the eye under examination.

3. Since any light which is reflected back through the pupil must return to the source whence it came, the observer's head must not obstruct the rays coming from the source of illumination.

The last difficulty has been ingeniously overcome by the invention of the 'ophthalmoscope,' by the aid of which we are enabled visually to explore the interior of the eye.

The fundamental principle of this instrument is that the eye of the observer shall be made, in a sense, the source of illumination.

In its essential features the ophthalmoscope consists of a circular (plane or concave) 'reflector' perforated by a central 'sight-hole.'

The surgeon, placing himself in front of the patient, at whose side is a lamp, adjusts the reflector to his eye in such a way that its 'sight-hole' corresponds to the axis of his own pupil, and receives on the bright surface the light from the lamp as he looks through from behind.

By properly tilting the instrument to the suitable angle, he can so direct the rays from the lamp through the pupil of the observed eye that its interior will be lighted up. The mirror may now be regarded as the source of light. The rays reflected back from the fundus will retrace their path of entry back to the mirror, and some of them, travelling through the sight-hole of the reflector, will enter the eye of the observer, and thus enable him to see the illuminated interior of the one he is examining.

An occasional half hour of good practical instruction will impart more information to the student than can be acquired by reading all the literature ever written on the subject.

Difficult of use at first, because great delicacy is required in its manipulation, constant practice with the ophthalmoscope on all available kinds of eyes, ranging from those of the domestic cat, dog, or rabbit, to those of the friend or patient, will soon give such a facility in its employment as to enable the details of a fundus to be seen with the same ease as our own face is recognised in a looking-glass.

Objective Examination of the Eye, and the Applications of the Ophthalmoscope.

The condition of the 'Refractive media' is to be first investigated, and afterwards that of the fundus. In all cases the following routine should be adopted:

1. { (*a*) 'Focal' illumination. / (*b*) Examination by 'transmitted' light. } For media.
2. { (*c*) Examination by 'indirect' method. / (*d*) Examination by 'direct' method. } For fundus.

These examinations should be conducted in a darkened room. The patient should be seated, and on the side corresponding to the eye under examination must be placed a lamp, giving steady and efficient illumination.

1. Examination of the Refractive Media.

(*a*) **'Focal,' 'Oblique,' or 'Lateral' Illumination,** for the detection of opacities in the media.

The lamp is placed at a convenient distance from the side, and slightly in front, of the patient's eye. The surgeon, facing the patient, by the aid of a strong biconvex lens (about 2-inch focus) held at the requisite angle, concentrates a cone of light laterally on the front of the eye. By altering the position of the lens, he can bring its luminous focus to bear successively upon cornea, aqueous, iris, pupil, lens, vitreous.

Small areas of brilliant illumination, circumscribed by shade, being thus brought into view, any moderate-sized opacity can be detected.

The focal length of the lens employed (2-inch) being known, if the opacity be brought to lie exactly in the plane of the focus, an estimate of its approximate depth may be made by noting the distance the lens must be moved nearer the eye in order to bring it into view.

For the detection of minute opacities, a supplementary biconvex lens of strong focal power can be held in the

disengaged hand at its focal distance from the area illuminated by the first lens. If then looked through, it serves as a powerful magnifying-glass, and will render visible opacities otherwise unrecognisable.

(*b*) **Examination by 'Transmitted' Light.**—The object of this method is also the detection of opacities in the media.

The lamp is so arranged that the patient's face is in shade, and the surgeon, with ophthalmoscope in hand, adjusts its reflecting-surface in such a way as to engage the rays of light, directing them thence into the eye of the patient. An orange-red 'reflex' should now be seen, and if opacities be present, they will appear as spots or dark shadows on the illuminated red background, the smaller ones being darker, as a rule, than large ones, for they reflect less light.

With the object of ascertaining the position of any given opacity, note if it moves spontaneously *whilst the head and eye of the patient are still*, for if it does, the opacity for a certainty is in the vitreous.

If it does not move, the opacity may be either in the cornea, aqueous, lens, or vitreous, in which case it must be either (*a*) in front of, or (*b*) behind, the pupillary plane, and it will undergo with reference to this plane, a parallactic displacement (*i.e.*, the apparent change of position of an object in relation to other objects when viewed from different places) *when the observer slowly moves his head*, such displacement being as follows:

In front of pupillary plane, moves 'against.'
Behind pupillary plane, moves 'with.'
If in pupillary plane, no displacement.

The more rapid and extensive the movement, the farther is the opacity from the pupillary plane.

The same results can be arrived at by reversing the procedure—the observer keeping his own eyes and head steady, and the patient being directed to move his—but inasmuch as the surgeon in all probability has his movements better under control than has his patient, the former is a more satisfactory and reliable method.

Opacities in the vitreous frequently change their position spontaneously, and they may have a wide range of movement. They are often especially noticeable after the patient has

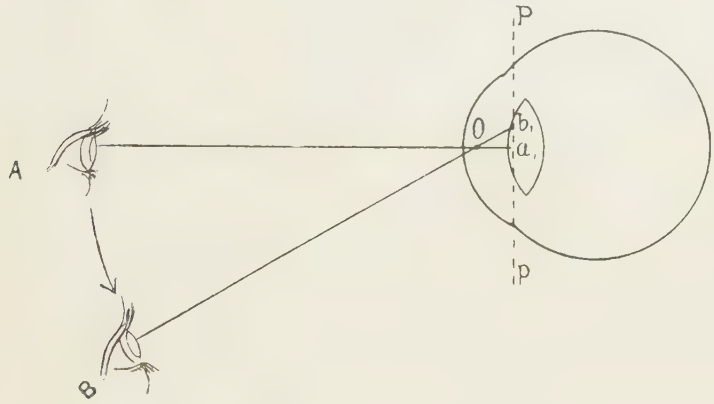


FIG. 52.

Opacity *o*, in front of *p p*, appears to move from *a* to *b*—*i.e.*, *against* the observer's eye.

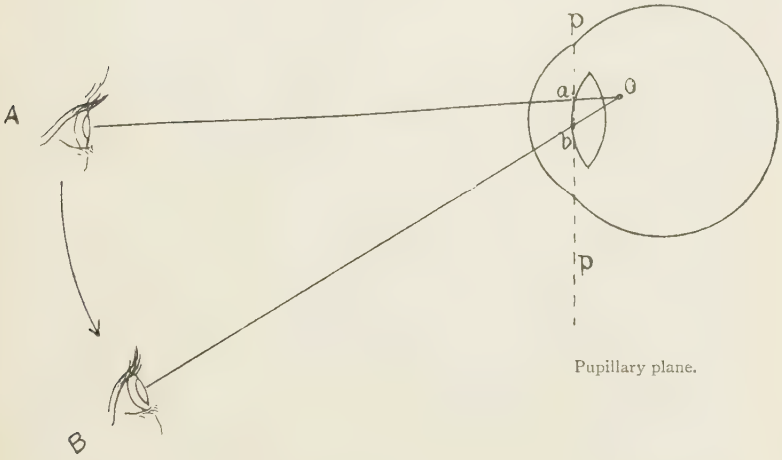


FIG. 53.

Opacity *o*, behind *p p*, appears to move from *a* to *b*—*i.e.*, *with* the observer's eye.

been directed to move the eyes rapidly in different directions. An opacity, even of minute size, once located, may be seen with great distinctness if behind the sight-hole of the reflector

there be placed a + glass, ranging in strength from + 6 D. to +20 D., the surgeon approximating his head to the eye of the patient until he comes within the focal distance of the lens used (*vide* fig. 58, p. 71). By this method of magnification, an opacity of very small size and otherwise invisible can often be accurately focussed, whether located in the cornea, aqueous, lens, or vitreous.

2. Examination of the Fundus.

If the interior of an eye be illuminated, the rays of light are reflected back from the fundus thus:

In emmetropia, parallel.
In hypermetropia, divergent.
In myopia, convergent (*vide* p. 66).

These return-rays can be made to afford, by means of the ophthalmoscope, either (*a*) an *indirect* view of the fundus, in which the parts are seen reversed, the principle involved being that of the compound microscope; or (*b*) a *direct* view, in which the parts are seen in their natural positions, the principle involved being that of a simple lens-system, and the media of the eye under examination furnishing a magnified image of the details of its own fundus.

(*c*) **The Indirect Method.**—The indirect method is concerned with the use of the mirror in conjunction with a convex lens, *the objective*, held between it and the eye to be examined, when an *inverted aerial magnified image* is formed *between the mirror and the lens*. By means of this examination, a good general view of the fundus can be obtained, and any of the grosser changes in it detected. As compared with the *direct method*, it affords a larger field, but less magnification (about 5 times as against $14\frac{1}{2}$ times), and it possesses the advantage that the fundus-picture is not rendered obscure by any errors of refraction in the patient's eye.

The *mirror* or *reflector* may be either *plane* or *concave;* if the latter, it should have a focal length of about 8 inches.

The *objective lens* is usually of about + 13 D.—*i.e.*, of a focal length of 3 inches, giving a magnification of the image of

about 5 times. The rays reflected from the surface of the *mirror* are made more *convergent* by the lens, and, entering the eye cross in the vitreous; hence the *field of fundus illumination* is less in the small eye of hypermetropia, and greater in the large eye of myopia, as compared with it in emmetropia.

The size of the image of any particular spot in the illuminated area depends chiefly on the strength of the *objective*, but also, though to a very slight extent, upon the refraction of the patient's eye. The rule is: the stronger the *objective*, the less the enlargement of the image, but the greater the field of illumination; the weaker the objective, the greater the enlargement, and the smaller the field of illumination.

In hypermetropia, the magnification is a little more, and in myopia a little less, than in emmetropia.

The greater the degree of myopia, the larger the field of illumination; the greater the hypermetropia, the smaller the field of illumination.

The objective should be scrupulously clean and free from scratches, as, otherwise, false interpretations with regard to what is observed may be made by the inexperienced.

A possible source of trouble may arise in connection with 'reflections' from the objective. This is best obviated by 'tilting.'

If the operator be ametropic, the necessary correcting lens should be in position behind the 'sight-hole.'

Preliminaries.—As before stated, the patient is to be seated in a darkened room, with the face turned forward, head erect and *kept absolutely still.* On the side corresponding to the eye under examination is the lamp, so arranged that the face is in shade. The surgeon adopts the 'face-to-face position,' seating himself exactly opposite at arm's length, the adjustable stool on which he sits being so regulated that the two heads are on the same level.

With his right eye the surgeon should learn to examine the right eye of the patient, and the left with his own left.

Procedure.—The ophthalmoscope is now brought into position, and its reflecting surface manipulated in such a manner

as to engage the rays of light from the lamp, and project them into the eye under examination. If this manœuvre be properly executed, the orange-red fundus reflex should be easily seen.

The *objective* is now taken between the thumb and forefinger of the disengaged hand, and held in front of the observed pupil at a distance corresponding to a little less than its focal length—*i.e.*, about $2\frac{1}{2}$ inches for an 'objective' of 3-inch focus; the hand may be steadied by resting the outstretched little finger on the patient's brow.

If 'reflector' and 'objective' be in correct adjustment, both with respect to one another and to the eye under examination, there should now come into view a *magnified, reversed, aerial* image of the fundus, *occupying a position between the 'reflector' and the 'objective'* but referred to patient's eye.

The chief landmark of the fundus is the nerve-head or optic disc, and this being situated 15° to the nasal side of the posterior pole, in order to bring it into view the patient is directed to look, whilst keeping the head still, towards the abducted little finger of the hand holding the ophthalmoscope.

If the operator is in the habit of always using the right hand and right eye, he must direct patient to look towards his left ear in the examination of the left eye.

Practice is required not only in projecting light from the 'reflector' into the pupil, but also in focussing accurately and keeping steady the 'objective,' for if this be moved whilst in position, the image of the fundus will be noticed to move *with* it; while if the operator move his head, the image of the fundus becomes displaced in the opposite direction. In connection with the *tilting* of the objective in order to avoid the reflexes from its surfaces, it is to be understood that if this *be excessive*, the result may be a considerable distortion of the image, thus making, for example, the image of a circular optic disc *appear oval*, a phenomenon that might be ascribed to astigmatism.

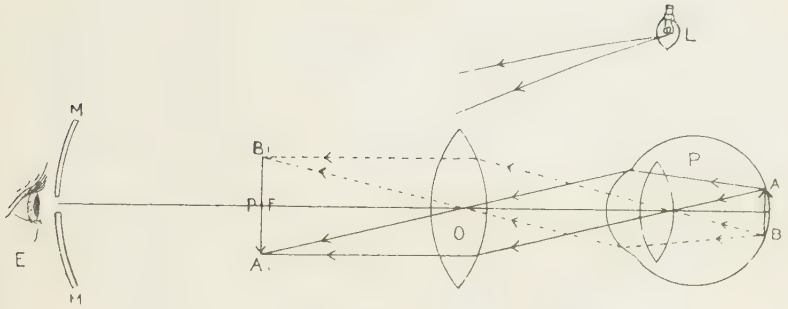


FIG. 54.

INDIRECT METHOD, EMMETROPIC EYE.

L, source of light; M M, mirror collecting rays from L, and by reflecting them into patient's eye P, illuminating its interior. The rays from any one point, A, will emerge from the eye parallel, because, since parallel rays entering an emmetropic eye are focussed on the retina, so rays diverging from a point on the retina will emerge parallel.

The rays from the point A, traversing the *objective lens*, O, will be brought to a focus at A_1 on the plane of its principal focus, PF. The same will happen to rays coming from the point B, which will be focussed at B_1. In like manner intermediate points on the retina lying between A B will be focussed on the same focal plane, B_1 A_1, and in this way will be formed an inverted, magnified, aerial image of this particular portion of the retina, of which the examiner's eye, placed in position, E, can obtain a view by looking through the hole of the mirror, M M.

If the patient's eye be hypermetropic, the emergent rays from his eye will be *divergent*, and the image formed by the objective lens will be *further off* from it than its principal focus; whereas, if the patient's eye be myopic, the rays from his eye will be *convergent*, and the image formed by the objective lens will be nearer to it than its principal focus. Hence the magnification of the inverted aerial image will be greater in hypermetropia, and less in myopia, as compared with it in emmetropia (*vide* Fig. 55).

(*d*) **Direct Method.**—The parts are here seen in their *natural position*, the principle involved being—to repeat—that of a simple lens-system in which the dioptric media of the observed eye furnish a magnified image of its own fundus.

Be it noted that the area of eye-ground lighted up by the ophthalmoscope corresponds to the size of the pupil, so that in order to obtain a larger field of illumination the pupil must be dilated.

The *mirror* alone is used in the *direct* method, and if the

operator have any ametropia, it must be corrected by bringing the necessary lens into position *behind the sight-hole;* in this manner he is made emmetropic.

The ophthalmoscope being held in the right hand for the examination of the right eye, and *vice versâ*, the *reflector* is manipulated in such a way as to collect the rays from the

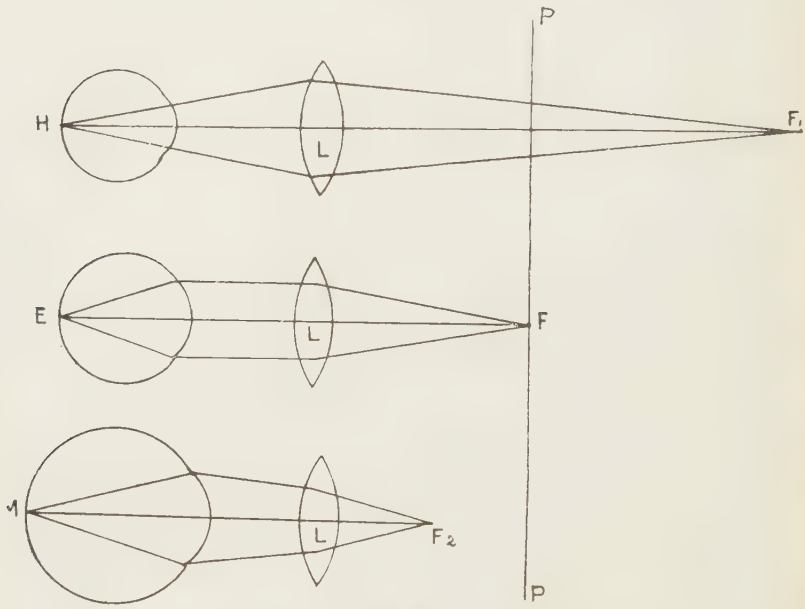


FIG. 55.

In *hypermetropia* the rays emerge *divergent*, and after passing through L, meet at F_1.

In *emmetropia* the rays emerge *parallel*, and after passing through L, meet at its principal focus, F.

In *myopia* the rays emerge *convergent*, and, after passing through L, meet at F_2.

P F P = focal plane of lens L.

lamp, which is placed a little more forward and farther out than in its employment for the *indirect* method.

The light impinging on the reflector is now projected from it into the eye of the patient. The fundus being thus illuminated, the operator advances his head until his eyebrow meets, or almost meets, that of the patient, so that the two corneæ are not more than 1 inch apart.

It is necessary, in order to obtain a satisfactory examination, *that the accommodation of both the observer and the patient be relaxed.* This requires considerable practice on the part of the former, as he is looking

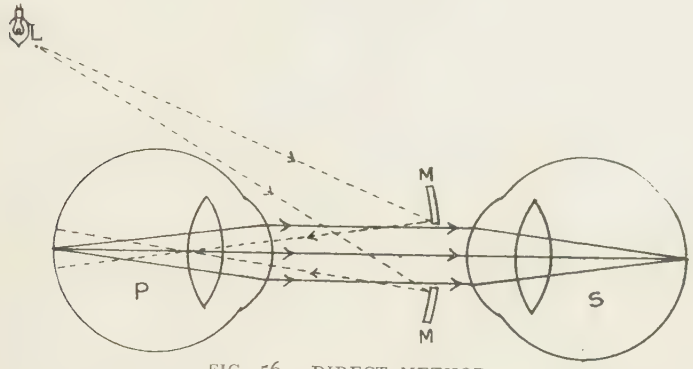


FIG. 56.—DIRECT METHOD.

Diagram showing how parallel rays emerging from the emmetropic eye of patient, P, are focussed on the retina of emmetropic eye of surgeon, S.

at a definite object; but it is not so in the patient's case. His eye is illuminated, but there is not on his retina a definite image of an object

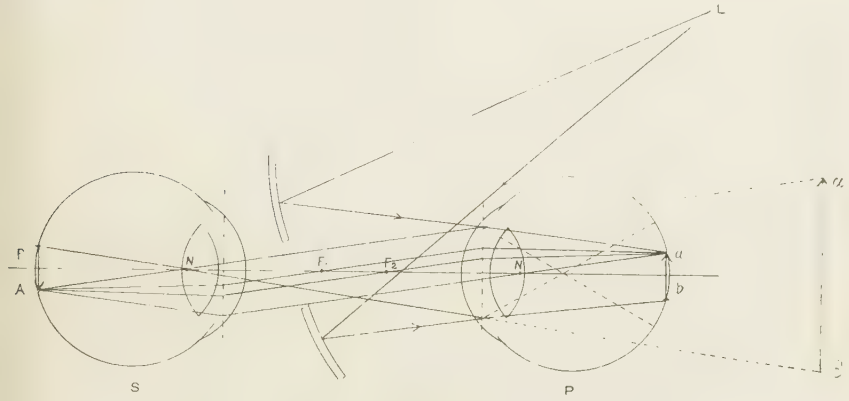


FIG. 57.—DIRECT METHOD.

Diagram showing how the rays of two pencils coming from the points *a* and *b*, on retina of patient's eye, P, have the optical value of coming from behind the eye at α and β, and forming an image, A B, on the retina of the observer's eye, S.

fixed, and in consequence the ciliary muscles physiologically retire to a position of rest, as they do when the eyes are closed, or as may be noticed when one is lost in thought and apparently gazing steadily at nothing.

Assuming that both operator and patient are emmetropic, and that their accommodation is suspended, a well-defined, *erect*, *real*, and *magnified* (about 14½ times) image of the fundus should now come into view, occupying a position apparently behind the eye.

Assuming the examiner to be emmetropic (or made so by placing the correcting lens behind the sight-hole), *and to be able completely to suspend his accommodation*, if he can see a clearly-defined image of the fundus of the examined eye, it proves this eye to be emmetropic. If, on the other hand, the details of such fundus are blurred (always provided the media be transparent), the eye in question has some defect of refraction, and the particular lens which, placed behind the sight-hole, renders the image clear and well-defined, will be the measure of the ametropia of the patient, convex glasses neutralizing hypermetropia, and concave ones myopia.

Determination of the Refraction by Means of the Ophthalmoscope.

1. *Indirect* method—quality.
2. *Direct* method—quality and quantity.
3. *Retinoscopy*—quality and quantity.

1. Indirect Method.

Focus the disc accurately and then slowly withdraw the 'objective'; then—

(*a*) If disc remains of same size and shape, there is emmetropia.

(*b*) If disc increases in size and retains its shape, there is myopia.

(*c*) If disc decreases in size and retains its shape, there is hypermetropia.

(*d*) If disc alters in shape, there is astigmatism.

(*e*) If there is decrease in size in one diameter alone, there is simple hypermetropic astigmatism.

(*f*) If decrease in size in all diameters, but unequally so, there is compound hypermetropic astigmatism.

(*g*) If increase in size in one diameter alone, there is simple myopic astigmatism.

(*h*) If increase in size in all diameters, but unequally so, there is compound myopic astigmatism.

(*i*) If decrease in size in one diameter and increase in size in the one at right angles to it, there is mixed astigmatism.

2. Direct Method.

By this means we can estimate both the quality and the quantity of defect.

(*a*) *Quality of Defect.*—If at a distance of about 18 inches from the eye under examination the individual vessels can be seen, and if, when the operator sways his head from side to side, the vessels move 'with,' there is hypermetropia; if 'against,' there is myopia.

(*b*) *Quantity of Defect.*—In measuring the amount of ametropia by this method, *a refraction ophthalmoscope* is required, and the surgeon must advance his eye as close *as possible to the eye of the patient.*

Be it remembered that if the

(*a*) *Surgeon* is (i.) *emmetropic*, his eye is adapted for *parallel* rays; if he is (ii.) *hypermetropic*, his eye is adapted for *convergent* rays; if he is (iii.) *myopic*, his eye is adapted for *divergent* rays.

In the case of (ii.) and (iii.) the optical defect must be neutralized by placing in position behind the sight-hole the necessary correcting glass, by which means his eye will be artificially made emmetropic.

On the other hand, if the

(*β*) *Patient* is (i.) *emmetropic*, the emergent rays will be *parallel;* if he is (ii.) *hypermetropic*, the emergent rays will be *divergent;* if he is (iii.) *myopic*, the emergent rays will be *convergent* (*vide* p. 66).

If the patient is *hypermetropic*, the *divergent* rays emerging from his eye will be rendered parallel by bringing into position behind the sight-hole a convex lens of the necessary power, by which means a clear image of the fundus should be obtained; and *if the correcting lens is situated in the anterior*

focal plane of the patient's eye (13·745 mm.=about $\frac{1}{2}$ inch from front of cornea), the strength of this lens will be the precise measure of the hypermetropia.

In practice, however, it is difficult, or impossible, to hold the correcting lens in the position of the anterior focal plane of the patient's eye, so that, under these circumstances, the correcting lens as established by the direct method *is slightly weaker than the real amount of the hypermetropia present.*

On the other hand, if the patient is *myopic*, the *convergent* rays emerging from his eye will be rendered parallel by bringing into position behind the sight-hole a *concave* lens of the necessary power, and if this is *in the anterior focal plane* of the patient's eye, the strength of this particular lens will be the exact measure of the myopia. But owing to the difficulty, as explained above, of holding the correcting lens in the position of the anterior focal plane, as established by the direct method, the lens which has to be used *is slightly stronger than the real amount of the myopia present.*

N.B.—It is assumed in all cases of estimating the refraction by the direct method that the accommodation both of surgeon and patient is relaxed.

The measure of the optical defect is the *strongest convex*, or the *weakest concave*, glass with which can be obtained a perfectly clear view of the fundus.

Examples.—(*a*) Surgeon has 2 D.H. Can see a clear picture of the fundus $\bar{c}+5$ D.

$\therefore$ Patient has $+3$ D.H.

(*b*) Surgeon has 2 D.M. Can see a clear picture of fundus $\bar{c}-5$ D.

$\therefore$ Patient has 3 D.M.

(*c*) Surgeon has 2 D.H. Can see a clear picture of fundus $\bar{c}-5$ D.

$\therefore$ Patient has 7 D.M.

(*d*) Surgeon has 4 D.H. Can see a clear picture of fundus $\bar{c}+3$ D.

$\therefore$ Patient has 1 D.M.

(*e*) Surgeon has 4 D.M. Can see a clear picture of fundus $\bar{C}+2$ D.

$\therefore$ Patient has 6 D.H.

In the correction of 'astigmatism' (a condition essentially due to unequal curvature of the meridians of the cornea), it is to be noted that *a given meridian of a spherical lens corrects the meridian at right angles to it*, the horizontal neutralizing the vertical, and *vice versâ*.

For the correction of astigmatism by the 'direct' method, the vessels running from the disc are employed as the test-lines.

Accordingly, the lens which brings into focus the vessels passing vertically from the disc will be the measure of the defect of the horizontal meridian of the cornea; while the lens which brings into focus the vessels passing horizontally from the disc will be the measure of the defect of the vertical meridian of the cornea.

We have assumed in the foregoing remarks that the refraction by the 'Direct' method has been taken at the yellow-spot. Now this part of the fundus is extremely difficult to focus with accuracy—a circumstance arising from its inconspicuous character—the 'fine stippling' of the retinal pigment being difficult to fix, even by the expert.

This being so, the landmarks taken are the optic disc, the vessels adjacent to it, and those skirting the yellow-spot. The results obtained are sufficiently accurate for all practical purposes.

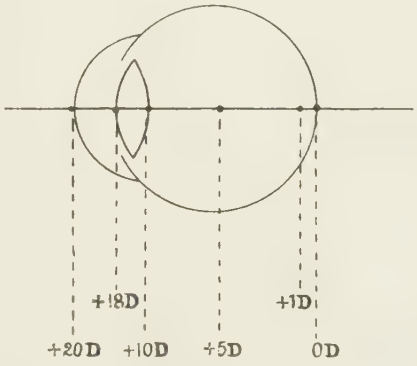


FIG. 58.

The refraction must not be taken in a region much removed from the posterior pole, as the more we recede from that point the more hypermetropic the fundus will become in hypermetropia, and the less myopic in myopia.

For exploration of the media as apart from the fundus, a +20D behind the sight-hole should enable the cornea and anterior chamber to be examined, a +18D the front of the lens, a +10D the back of the lens, and the vitreous from +10D to +1D according to depth (*vide* diagram 58).

EXPLANATION OF THE MAGNIFICATION OF THE OPHTHALMOSCOPIC IMAGES.

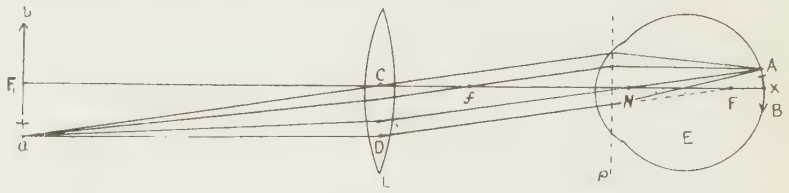


FIG. 59.

Magnification of Image by Indirect Method.

Let A B represent an illuminated area (*e.g.*, optic disc) in the observed eye, E. Let L be the convex lens used, of focal length 75 mm., and let its focal points be F F_1, and C be its optical centre. Let *f* be the anterior focal point of the eye E, and N its nodal point, *p* being its principal plane.

Construction.—A ray parallel to the optic axis is refracted at *p* through f. Another ray from A will pass through C, and be unrefracted in L. A N is a ray passing through N without refraction. Some other ray (A D) will come from A, and be refracted at *p*, whose direction (backwards) will cut the axis at F. These four rays, on emerging from the eye, will be parallel if E be emmetropic (as is supposed). This parallel pencil, after refraction, will come to a focus at *a* in the principal focal plane of L, and here will be formed an inverted real aerial image (*a b*) of A B.

Magnification.—By construction, $F_1 a = C D$. Now consider the two triangles C F D and A N X. It is evident that they are similar, and $\therefore$ C D : A X :: C F : N X, but C F : N X :: 75 : 15—*i.e.*, 5 : 1. Hence the aerial image is magnified 5 times with this particular lens.

Magnification of Optic Disc in Direct Close Method.

In Fig. 60, L is the source of light, and rays from this, falling upon the concave mirror, are rendered convergent, and more so on entering the eye, so that they cross in the vitreous and illuminate diffusely* an area bounded by the dotted lines, as shown. Assuming both eyes to be emmetropic, and drawing one ray in each eye parallel to the axis, and refracted through its anterior focal point F, and one ray in each through its nodal point N undeviated, an inverted image (A B) is formed of an illuminated part (*a b*) of the observed retina, and of exactly the same size. Since all objects looked at produce inverted retinal images, it follows that *a b* is *seen upright*, the erection of the image being an unconscious psychological process; really an acquired habit from

* When L occupies a certain position, a real image of it is formed on the retina of D by the action of mirror and lens.

experience. (For the sake of clearness, only one of the rays from *b* is drawn to B.)

If *a b* be taken to represent the optic disc, ·9 mm. in diameter, then the

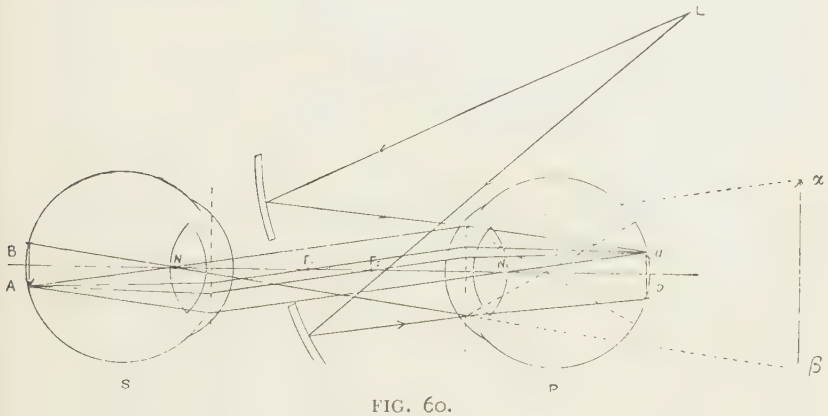


FIG. 60.

image A B is ·9 mm. in diameter. The question now arises: What size does the object producing this retinal image *appear* to be?

From Fig. 61, it is evident that many objects of different sizes (a_1 b_1, a_2 b_2, a_3 b_3, etc., may produce the same-sized retinal image if the distance be properly adjusted. The sun at 93 million miles, the moon at 239,000 miles, and a halfpenny at 9 feet, all produce retinal images of the same size. Hence it is plain that before the eye can judge the size of an object a previous estimate (always unconscious) of the distance has to be made, and *vice versâ*.

The sun and moon, when near the horizon, always seem larger than when higher. They are seen to be away behind the farthest trees or

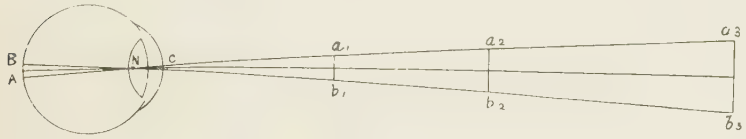


FIG. 61.

housetops, also their light is dimmer, and these two appearances suggest that they are further off than usual; therefore they are judged to be larger, though their retinal images are always the same size. Again, if a person is suddenly encountered in a fog in a place where there are no familiar objects (an open field, for instance), he appears to be a veritable giant. Being dimly seen, and his approach not having been heard, he is immediately estimated to be far off, but the retinal image is that of a man close to; therefore he is judged to be larger.

Now, in the close examination of the upright image, the examiner knows the illuminated object, the optic disc, to be less than 3 inches away from his own eye, but since he cannot see clearly objects so close

as this—8 inches, or 20·3 cm. being (normally) his nearest distance of distinct vision, (20·6 cm. from the nodal point)—he judges the image to be at this distance. What size then does it appear? The image is 14 mm. behind the nodal point, and the object is set down as being 206 mm. in front of it; hence we have (Fig. 61) $a_1 b_1 : A B :: 206 : 14$—*i.e.*, the magnification is $\frac{206}{14} = 14{\cdot}6$ times, and the disc appears to be $9 \times 14{\cdot}6 = 13{\cdot}2$ mm. in diameter, or about the size of the iris. The apparent size, of course, varies with individuals. The magnification would be 10 if the near-point of the observer were $5\frac{1}{2}$ inches (140 mm.) distant.

If the examined eye be myopic, a clear view of the fundus is obtained when the necessary correcting glass (concave) is in position behind the sight-hole, but this is always further from the patient's eye than the anterior focal plane, 13·7 mm.—the plane in which his spectacle-glasses should be worn. The lens is nearer the myopic far-point—*i.e.*, its focal length is shorter, or its power greater than that of the lens required. Hence the rays from the patient's fundus entering the observer's eye are divergent instead of being parallel, and the magnification rather greater than in emmetropia.

In hypermetropia, the patient's far point is behind his eye, so that the convex lens behind the sight-hole has too long a focal length—*i.e.*, it is weaker than the lens required; hence the magnification is somewhat less.

3. Retinoscopy or the Shadow-Test: the Method of Cuignet.

Retinoscopy is the method of determining the refraction of the eye, both qualitatively and quantitatively, by reflecting into it light from an ophthalmoscopic mirror, and observing carefully the *play of light and shade in the pupil* as the reflector is rotated. The method possesses two great advantages:

(*a*) Accommodation on the part of the surgeon does not influence the result as it does when the refraction-ophthalmoscope is employed.

(*b*) The method being entirely objective, errors of refraction can be worked out without assistance from the patient, a fact of great value in the case of children and those unable to read.

Inasmuch as we desire *to estimate solely the static refraction*, for the results to be reliable, the eyes, before examination, should be brought under the influence of a mydriatic, so as

to eliminate the possibility of accommodation on the patient's part.*

Speaking generally, it may be laid down as a rule that up to the age of twenty, atropine (4 grs. to the oz.) should be used for each eye three times a day for one week; from twenty to twenty-five twice a day for three days will suffice; after this age, one application of homatropine and cocaine is all that is necessary (*vide* Appendix).

The lamp is usually placed above the patient's head and far enough back *to keep the face in shade.* Affixed to the face is the trial-frame. As each eye is to be tested separately, it is necessary to exclude by an opaque screen the one not under examination for the time being; this is especially important in cases of squint. The retinoscopy mirror may be either:

(*a*) *Concave*, or
(*b*) *Plane.*

(*a*) **The Concave Mirror** should have a focal length of about 22 cm., and be perforated by a central aperture with a diameter of about 3 mm.

The surgeon seats himself directly opposite the patient on an adjustable stool so that the two heads may be on the same horizontal plane. He must 'sit square' to the patient, at a distance of about 4 feet.† (If he be ametropic he need not wear his correction unless he is unable to see the pupil clearly at this distance.) The light is now reflected from the lamp into the patient's eye, and *as it is the refraction along the visual axis (i.e., in the plane of the yellow-spot), which is required*, he is directed to look, with eyes wide open, *straight at the hole in the mirror.* It will now be found that when the mirror is slowly rotated from side to side or from above downwards, two appearances are noted, if, as we assume, the media be clear:

(i.) An *orange-red area of illumination*, the fundus-reflex; and

* It is the refraction *at the yellow-spot* that is required, not that at the optic disc, the two not being usually in the same plane. Light falling on the yellow-spot causes the normal pupil to contract. An additional advantage then of using atropine is that it allows the refraction at the yellow-spot to be measured.

† The best distance is 1 metre plus the focal length of the mirror.

(ii.) A *shadow*, creeping from behind the pupil, and forming the boundary of the fundus-reflex. It is to the *edge* of this shadow and its movements that attention is to be particularly directed.

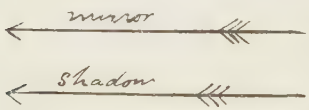
FIG. 62.

Note.—Used in this connection, the term 'shadow' may be somewhat misleading. As employed in retinoscopy, the word does not imply that the shadow of an actual object is cast upon the retina. It applies strictly to the *boundary of the illuminated area*—that is, to the junction of the illuminated and non-illuminated regions.

The shadow may move either in correspondence to the movement of the mirror, when it is said to move *with* it; or it may move in opposition to the mirror, when it is said to move *against* it.

The *rate of movement*, the *direction* and *distinctness* of this shadow, together with the *brightness* of the fundus-reflex, indicate the refraction of the eye.

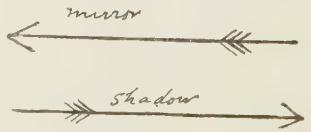
Axiom.—The edge of the shadow is always perpendicular to that meridian of which the refraction is being investigated. For example, if the light be swept across the cornea horizontally from right to left, and the edge of the shadow be at right angles to this—*i.e.*, vertical—the refraction of the *horizontal* meridian is indicated; while, again, if the light be swept across the cornea from above downwards, and the edge of the shadow be horizontal, the refraction of the *vertical* meridian is indicated.



If the shadow move *with*, the meridian in question is undoubtedly *myopic*; to this rule there is no exception.

On the other hand, if the shadow move *against*, the meridian under investigation may be either:

(α) Slightly myopic,
(β) Emmetropic, or
(γ) Hypermetropic.



In the case of (*a*), if +·50 D. be placed in the trial-frame, and the direction of movement of the shadow be reversed—*i.e.*, if it now move *with* the mirror—*myopia* not exceeding 1 D. is indicated.

In the case of (*β*), if +1 D. be placed in the trial-frame, and the direction of movement of the shadow be reversed—*i.e.*, if it now move *with* the mirror, while it will not move with the mirror with +·50 D.—this shows *emmetropia*.

In the case of (*γ*), if +1 D. be placed in the trial-frame, and the direction of movement of the shadow be unaltered—*i.e.*, if it still move *against* the mirror—this indicates *hypermetropia*.

Axiom.—The *brightness* of the fundus-reflex is always in inverse ratio to the amount of ametropia.

Also, if the fundus-reflex be *brilliant*, and the shadow move *quickly*, with its edge *well-defined*, the ametropia, if present, is of low degree.

On the other hand, if the fundus-reflex be *dull*, and the shadow move *slowly*, with its edge *ill-defined*, the ametropia is of high degree.

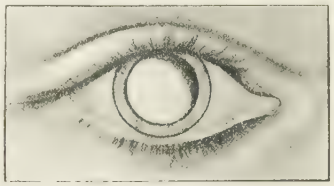


FIG. 63.—ASTIGMATIC SHADOW.

Astigmatism.—If, in two opposite meridians, the rates of movement and also the character of the shadows differ, *astigmatism* is present.

If, on rotating the mirror on its vertical or horizontal axis, the edge of the shadow is found to be *slanting* (Fig. 63), astigmatism is again indicated, and in order to estimate the defect, *the mirror is to be rotated at right angles to the slanting edge* of the shadow, the examiner always bearing in mind that the meridian under investigation is perpendicular to the edge of the shadow.

Amount of Refractive Error.

The Correcting Lens—*Principle I.*—A movement *with* the mirror, under all circumstances (with or without a glass), indicates that the eye is *myopic*, either artificially or naturally.

Principle II.—A movement *against* the mirror is compatible with myopia of a degree not exceeding 1 D.

Hence, from Principle I. it follows that the convex lens which just reverses the direction of movement of the shadow in hypermetropia (*i.e.*, makes it go *with*), has made the eye myopic, so that the refraction is *over-corrected;* and from Principle II. it follows that the concave lens, which just reverses the direction of movement of the shadow (*i.e.*, makes it go *against*) is an *under-correction*.

Accordingly, if 1 D. be taken as the allowance to be made, −1 D. must be added to all the results obtained by retinoscopy. This will *decrease* the *hypermetropia* by 1 D., and *increase* the *myopia* by 1 D.

For example, suppose +4 D. *just reverses* the direction of movement of the shadow in a case of hypermetropia, then 3 D. would represent the amount of the defect actually present; while if −4 D. just reverses the direction of movement of the shadow in a case of myopia, −5 D. would represent the amount of defect actually present.

Influence of Atropine

It has been pointed out in an earlier chapter that emmetropia is that condition of refraction in which, with accommodation *physiologically* relaxed, parallel rays are focussed on the retina. Now, atropine actually paralyzes the ciliary muscle, causing a loss of the so-called *tone*, and the degree of relaxation produced by it is in excess of that ever occurring under physiological conditions. This artificially-induced paralysis, by allowing the ciliary processes slightly to recede (*vide* diagram, p. 44), tightens the suspensory ligament, and thus makes the anterior surface of the crystalline lens more compressed than it ever is naturally, *thereby diminishing its refractive power*. Obviously, this result is greater in the case of the strong ciliary muscle of the hypermetrope than in the weak ciliary muscle of the myope. Hence, in the former instance it is customary to *add about* −1 D. (in children sometimes as much as

−1·50 D.), and in the latter about −·50 D. (sometimes a little less, and sometimes a little more, the limits being from −·25 D. to −·75 D.).

It follows that we arrive at the practical rule that convex glasses should be weaker by about 1 D., and concave glasses stronger by about ·50 D., than the amount ascertained under atropine. These remarks, of course, apply more particularly to young people in whom the accommodation is powerful. After thirty, the influence of atropine is of but little account.

Hence, in hypermetropia of a young subject, if +6 D. *just reverses* the direction of the movement of the shadow, we have:

+6 D.
add −1 D. for over-correction
add −1 D. for effect of atropine
+4 D. — the full correction.

In myopia, if −6 D. just reverses the direction of movement of the shadow:

−6 D.
−1 D. for under-correction
− ·50 D. for effect of atropine
−7·50 D. = the full correction.*

(*b*) **The Plane Mirror.**—In practising retinoscopy with the plane mirror, the observations are to be made under the same conditions as those which obtain in using the concave mirror, but the distance should be increased to 5 feet. The *direction of movement of the shadow is exactly the reverse of that found when using the concave mirror,* but in all other respects the indications are the same (*vide* p. 78).

* Many myopes of 6 D. and over cannot accept their full retinoscopic correction when tried at the distant test-types, owing to the combined effect of an impaired retina and the minified images caused by concave glasses (*vide* chapter on Treatment of Myopia).

Summary.

(*a*) *With Concave Mirror.*—The shadow moves *against* in *emmetropia, hypermetropia, myopia of less than* 1 D.; and *with* in *myopia of more than* 1 D.

(*b*) *With Plane Mirror.*—The shadow moves *with* in *emmetropia, hypermetropia, myopia of less than* 1 D.; and *against* in *myopia of more than* 1 D.

In hypermetropia and myopia the results are the same for all meridians.

In *astigmatism* the two chief meridians are usually *horizontal* and *vertical, but they may be oblique*, and the diagnosis of this condition is based upon the following observations:

Whether (i.) the shadow move more quickly in one chief meridian than in the other; or

(ii.) The edge of the shadow be oblique; or

(iii.) The shadow move *against* in one chief meridian and *with* in that perpendicular to it—whether, that is, the astigmatism be *a mixture* of hypermetropia and myopia (*mixed astigmatism*).

In all cases *the mirror is to be rotated at right angles to the edge of the shadow.*

The refraction of the meridian under examination is always parallel to the direction of rotation of the mirror—viz., at right angles to the edge of the shadow.

The *exact degree of obliquity* of the shadow cannot be determined by retinoscopy. Its position must be settled by placing cylinders in the trial-frame, and finding the exact axis with which vision at the *distant test-type is best.*

In whichever way the mirror be rotated, *the apparent movement* of the shadow is always in the direction of the nearest chief meridian, and at right angles to the edge of the shadow.

The lens which just reverses the shadow is an over-correction for hypermetropia and an under-correction for myopia to the extent of about 1 D. in each case.

An allowance of about 1 D. must be made for the effect of atropine in hypermetropia, and of about ·50 D. in myopia.

This will decrease the apparent hypermetropia by 1 D., and increase the myopia by ·50 D.

	Ametropia.	Rate of Motion.	Width of Shadow.	Border of Shadow.	Direction.	Fundus Reflex.
1	High myopia	Slow	Narrow	Ill-defined	With	Dim
2	Low myopia	Quick	Broad	Sharp	With	Bright
3	Emmetropia	Quick	Broadest	Sharp	Against	Bright
4	Low hypermetropia	Quick	Narrow	Very sharp	Against	Bright
5	High hypermetropia	Slow	Very narrow	Sharp	Against	Dim

It must be understood that the results obtained by this method cannot be regarded as absolutely correct, but are within ·50 D. They must in all cases be verified at the distant test-types.

THEORY OF RETINOSCOPY.

Let L be the source of light and M a concave mirror, with its centre of curvature at C, and focus at F about 20 cm. from M. There will be an image of L formed at I, a little above and to the right of F. Let *i*

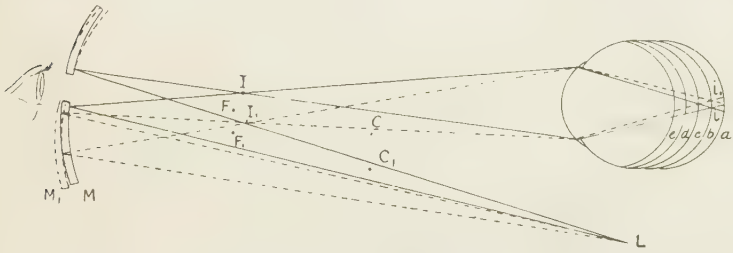


FIG. 64.

represent the image formed on the retina *b*; then it follows that retinæ in other positions, as *a*, *c*, *d*, *e*, will have diffusion circles of light formed upon them.

If I be the far point of the eye, then it is one of low myopia, I being distant about 1 metre, and the position of the retina will be that of *b*. In the other cases represented—*a*, high myopia; *c*, emmetropia; *d*, low hypermetropia; *e*, high hypermetropia—diffusion-circles are formed proportional in size to the amount of ametropia.

When the mirror is tilted downwards (into the dotted position M_1), I goes to I_1; and by laws established in Chapter I., p. 9, *i* goes to i_1—*i.e.*,

against the mirror. Also, all the aforesaid diffusion-circles go the same way—*against.*

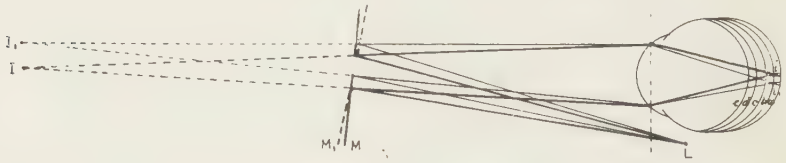


FIG. 65.

If M be the position of the mirror (plane), then an image (virtual) of L is formed at I (as far behind M as L is in front) and an image (real) of I is formed at *i* on the retina *b*, diffusion-circles being formed on retinæ in other positions, as *a*, *c*, *d*, *e*. When the mirror is rotated downwards to the position M_1, then I goes to I_1, and *i* goes to i_1—*i.e.*, downwards—and the diffusion-circles go the same way. This is just the opposite of what takes place with a concave mirror (see Fig. 64). *b* is the retina of a low myopic eye whose far-point is at I.

Now, having seen how the retina in the observed eye receives its illumination, and that this always moves *against* the concave mirror, let us omit from subsequent diagrams all the rays concerned in the formation of this illuminated area, and consider only those which leave the retina, pass through the lens, and enter the eye of the observer, and we shall take the five cases mentioned and consider each separately.

(*a*) **High Myopia.**—Here we have a diffusion-circle, *a b*, upon the retina, because it is further back than the focal plane of the refracting media of the eye, the rays having crossed at *i* (Fig. 64), and an image of this circle is formed in the air at $\alpha\ \beta$, as shown in Fig. 66, the construction

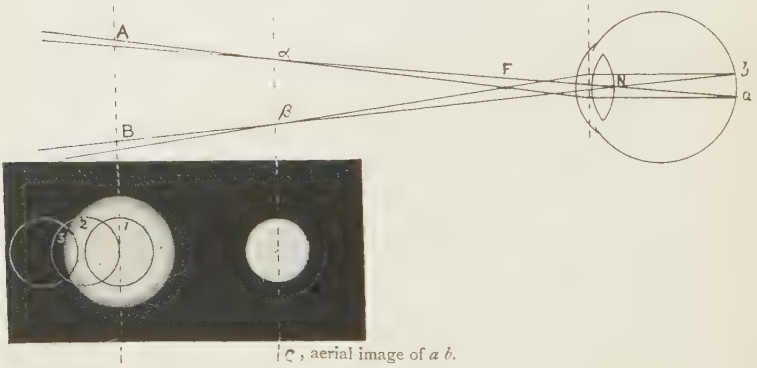


FIG. 66.

being to draw a ray through the nodal point undeviated, and another parallel to the axis, and refracted at the principal plane through the anterior focal point F. Such rays cross at $\alpha\ \beta$, and here is formed a real aerial

image of *a b*. Since the observer is accommodated for the pupil, and not for the image, its edge appears ill-defined, as shown in the figure.

Suppose now, by a downward tilt of the mirror, *a b* is made to go to $a_1 b_1$ (Fig. 67), then the emergent cone of rays, A F B and the image

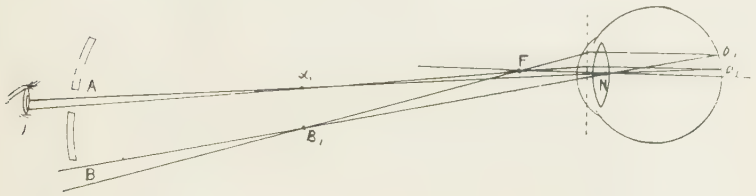


FIG. 67.

$a_1 \beta_1$, goes downwards—*i.e.*, sweeps across the front of the mirror—and presently the more or less ill-defined edge of the cone sweeps across the sight-hole, and, when it is just passing, the eye behind the hole sees the light disappear downwards, followed by the concave edge of the shadow, and the field of vision—*i.e.*, the observed pupil—at different stages of the sweep is represented by the circles 1, 2, and 3 in Fig. 66. Owing to the largeness of the diffusion circle, *a b*, the illumination is seen to be somewhat feeble, and the shadow is not very wide.

(*b*) **Low Myopia.**—Here the cone of rays is not so divergent, for, as we approach emmetropia, they become more and more nearly parallel, the section of the cone is smaller, the illumination brighter, and the edge of it more curved than before and the width of the shadow greater.

(*b*) 1. *Particular Case of Low Myopia* in which the far-point, P, coincides with the focus of the mirror. On account of this coincidence, there is formed on the retina of the observed eye an exact and well-defined

FIG. 68.

image, *i*, of F (which in its turn is an image of L, Fig. 64). Hence the rays emerge from the image in the eye along the same path as they entered, P and *i* being conjugate foci.

The shape of the emergent beam is shown in Fig. 68, and it is seen that the cone is very narrow in section, and may even all be included in the sight-hole of the mirror. The illumination is a maximum, and a *very slight* movement of the mirror is enough to send the cone right off the sight-hole, as shown by the dotted lines, and so the edge of the shadow is difficult to observe (be it noted that a reflected ray moves at *twice* the angular rate of the mirror).

Now, since we have assumed the distance P E to be 1 metre, it is obvious that a – 1 D. lens, placed in front of the eye, would remove the far point to infinity—in other words, render the rays parallel. Hence this is

a case of myopia 1 D., and it may be regarded as the limiting case between movement *with* and movement *against*.

(*b*) 2. *Myopia of less than* 1 D., in which the remote point lies further away than P is not often met with in practice, as so little inconvenience is experienced that it is hardly worth correcting, being actually a real convenience for close work like reading, etc., and cannot be accurately gauged by the method of retinoscopy, as the movements of the shadow are difficult to observe, for the same reasons as before. Such cases must be settled at the test-types.

(*c*) **Emmetropia.**—In this case the diffusion circle of illumination is very small (see Fig. 64), and is situated at the principal focus of the eye, so that the emergent beam consists of bundles of parallel rays coming from points of light in the circle. The section of this beam is nearly the same at every point, and is about the size of the patient's pupil. The illumination, as seen by the observer, is bright, but the shadow movement, which is 'against,' is not easy to detect, for reasons already given.

(*d*) **Low Hypermetropia.**—Rays from any point of light in the circle of illumination continue to be divergent after passing out of the eye, and so never cross as in case *a* (myopia), but their directions, if produced backwards, do meet, and form a virtual image of the point, behind the eye. This is shown in Fig. 69, and is the reason why the shadow moves against instead of with.

$\alpha\ \beta$ is a virtual image of $a\ b$ (see Fig. 14, Chap. I.). As in all the other cases, when the mirror is tilted down, $a\ b$ goes up, and therefore, also, $\alpha\ \beta$. In Fig. 69, $a_1\ b_1$ is the new position of $a\ b$, and $\alpha_1\ \beta_1$ of $\alpha\ \beta$. This is movement against. The appearance seen is represented by the shaded

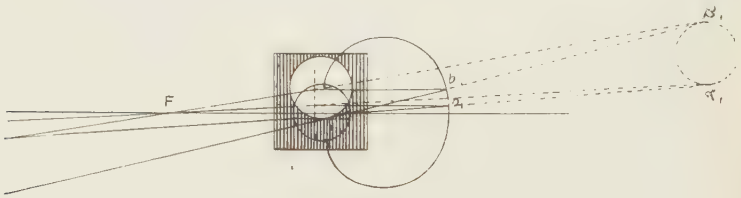


FIG. 69.

projection, where the lower circle represents the pupil, and the upper the virtual image $\alpha_1\ \beta_1$.

(*e*) **High Hypermetropia.**—In this case the diffusion-circle of illumination is larger, and the emergent rays more divergent than in *d*. Hence, also, the virtual image $\alpha\ \beta$ is larger, and, therefore, not so bright, and, being larger, the shadow more crescentic. These results are summarized on p. 81.

CHAPTER V

THE NORMAL FUNDUS AS SEEN WITH THE OPHTHALMOSCOPE

Definition (*fundus*, foundation).—The term *fundus* may be defined as the cup-shaped hollow of the sclerotic, lined by two superimposed layers, the choroid and retina, and pierced behind by the termination of the optic nerve.

Anatomical.—The sclerotic is to be regarded as an extension of the dura mater; the choroid, of the pia mater; and the retina, of the brain.

The *choroid* is an intensely vascular, loose connective-tissue web, the cells of which contain abundant pigment, *to insure the internal darkness of the eye.* Behind, it is continuous with the pia mater, and in front is prolonged into the ciliary processes and iris, the whole expansion constituting the *uveal tract.*

The *retina* varies in thickness from ·4 mm. at the posterior pole to ·2 mm. at the anterior part, and morphologically consists of two distinct portions in close contact:

(*a*) An outer pigmented layer, adherent to and partially concealing the choroid, and representing the non-invaginated part of the 'optic vesicle'; it is composed of a single layer of hexagonal cells (·015 mm.), loaded with the black 'fucsin' crystals.

(*b*) An inside non-pigmented portion, representing the invaginated portion of the optic vesicle; it consists of the following layers, counting from before backwards: Internal limiting membrane, nerve-fibre layer (axis cylinders only), layer of ganglion cells, inner molecular layer, inner nuclear layer, outer molecular layer, outer nuclear layer, external limiting membrane, rods and cones.

The *rods*, which number about 130,000,000, and the *cones*, numbering about 3,360,000, are *the special nerve terminations.*

The retina has its own independent system of bloodvessels, *which lie principally beneath the nerve-fibre layer*, and are quite separate from those of the choroid. The arteries, like those of the brain, are *terminal*, a fact which explains the blindness of the area supplied by them which ensues after thrombosis or embolism, also their proclivity to rupture.

The function of the pigment in the retina and choroid is to absorb the light that has passed through the layer of rods and cones, and *so prevent any internal reflection* from the white, glistening sclerotic.

Ophthalmoscopic Appearances.

The pattern of the fundus of the two eyes generally corresponds.

Magnification.—It is to be noted that with the *Indirect* method the different parts of the fundus are seen *reversed and magnified about* 5 *diameters;* while with the *Direct* method they are seen in *their natural position and magnified about* $14\frac{1}{2}$ *diameters.*

Fundus Reflex.—The orange-red fundus reflex, or illuminated eye-ground, is essentially *a red reflex from the choroidal blood*, somewhat toned down by the pigment in the retina and choroid. Its particular tint may be said to harmonize with the complexion and the colour of the hair, being light or dark in accordance with the amount of pigment in the skin, *for there is a distinct correlation between skin-pigment and eye-pigment.*

Thus the particular tint of the fundus will vary from the light orange observed in the blonde with fair skin and hair, to the deep chocolate or slate colour of the dark-complexioned races.

The essential portion of the healthy living retina—the non-pigmentary—is, with the exception of its bloodvessels, *transparent and invisible*, and any loss of this transparency implies disease. The capillaries of the retina are the smallest in the body, and cannot be seen by the ophthalmoscope, either individually or collectively.

The colouring matter in the pigmentary layer is, as a rule, sufficiently dense and opaque to conceal from view the *outlines* of the subjacent choroidal vessels; it may, however, be scanty, and then they can be seen.

Pigmentation.—The pigment in the choroid is under ordinary circumstances distributed uniformly, though it may sometimes be seen as an irregular mosaic, being massed in definite areas enclosed within the meshes of a pink network formed by the anastomosing choroidal vessels. In fair-complexioned subjects the pigment areas may be even lighter in tint than the vessels themselves.

Bloodvessels.—When we speak of the bloodvessels of the fundus we refer *to the columns of blood in them;* the vessel-walls themselves are invisible unless diseased, as is proved by the fact that when, by pressure on the globe with the finger, a vessel is rendered bloodless, no trace of its walls can be seen.

No vessel with a diameter of less than $\frac{1}{700}$ inch is visible (Gowers), much less capillaries (the average diameter of a capillary is only about $\frac{1}{3000}$ inch). The upper or lower branch of the central artery of the retina, which appears comparatively large as seen with the ophthalmoscope, is in reality only about $\frac{1}{100}$ inch in diameter.

Optic Disc.—The most conspicuous landmark in the cup-shaped hollow of the fundus is the intra-ocular termination of the optic nerve, commonly known as the 'optic disc' or 'nerve-head.' Paler than the surrounding choroid, in many cases it somewhat roughly suggests a full moon; it is easily recognised by its rounded outline and whitish core, and by the branching vessels which emerge from it. The term 'papilla' formerly applied is a misnomer, as under normal conditions it does not project. *Its tint is always redder in the young than the old*, and it is

an ophthalmic maxim that its shade may be as varied as that of the cheek.

The usual shape of the disc is circular or oval, and although much magnified by the ophthalmoscope, its actual diameter is said to be about 1·5 mm., and its position some 15° to the nasal side of the posterior pole, so that in order to bring it into view the cornea must be turned a little inwards towards the nose.

The border of the disc is sharply defined, except in 'optic neuritis' and certain cases of astigmatism ; and it exhibits an outer pink zone (due to the presence of numerous capillaries) surrounding a whitish central core.

Colour of Disc.—In young subjects the colour may be as rich as that of the surrounding field, whereas in old people it may, like the complexion, be pale.

If the fundus contain abundant pigment, the disc may by contrast appear quite white. As a rule, the distribution of capillaries in the disc is in direct proportion to the number of nerve-fibres in any given area, and inasmuch as there are more fibres on the nasal side in correspondence to the greater size of the temporal half of the field of vision, *the inner part of the disc is more highly coloured than the outer.*

Scleral Ring.—Sometimes, and more especially in old people, the disc is seen to be encircled by a pale ring, complete or incomplete, and usually not of uniform thickness, being wider, as a rule, below. It is generally known as the 'scleral ring' ; but this term is misleading, as the appearance is in reality due to a band of connective tissue which surrounds the head of the optic nerve in the same way as a piece of cotton or string encircles the stalks of a bunch of flowers.

Choroidal Ring.—External to the scleral ring, either in conjunction with it or not, may sometimes be noticed another ring, the 'choroidal ring,' black in colour, and caused by the heaping up of pigment along the annular margin of the choroidal aperture. The pigment may form a complete circle, but the ring is frequently defective in places, being usually massed mostly along the outer side, and it then may take the shape of a *black crescent*, liable to be mistaken by the inexperienced for a pathological change. Each of these rings is often absent.

Physiological Cup (Fig. 70).—In the pale central part of the disc the floor is generally sunk below the surrounding level, giving rise to a funnel-shaped depression—the *physiological cup.* The size, shape, and depth of this cup all vary within somewhat wide limits ; sometimes it is so small as to be barely recognised, while in extreme cases it may be so large that by the inexperienced its boundary may easily be mistaken for the actual border of the disc. *It never occupies, however, the whole of the area of the nerve-head,* for on careful inspection *it can always be seen to be surrounded by a distinct pink belt of disc margin.**

In consequence of the floor of the cup being below the level of the surrounding fundus, the observer, on moving his head from side to side, will notice a *parallactic displacement* of the parts.

Formation of the Physiological Cup.—The *lamina cribrosa*

* In glaucoma the cupping involves the entire optic disc, and the edges are undermined, which they never are in physiological cupping.

(*cribrum*, a sieve), or spot at which the optic nerve fibres pierce the globe, consists only of the inner third of the thickness of the sclerotic, the outer two-thirds peeling off and blending with the outer sheath of the nerve. Just before entering the lamina cribrosa, the 500,000 medullary sheaths of the optic nerve fibres abruptly end—just as the sleeve ends at the wrist—

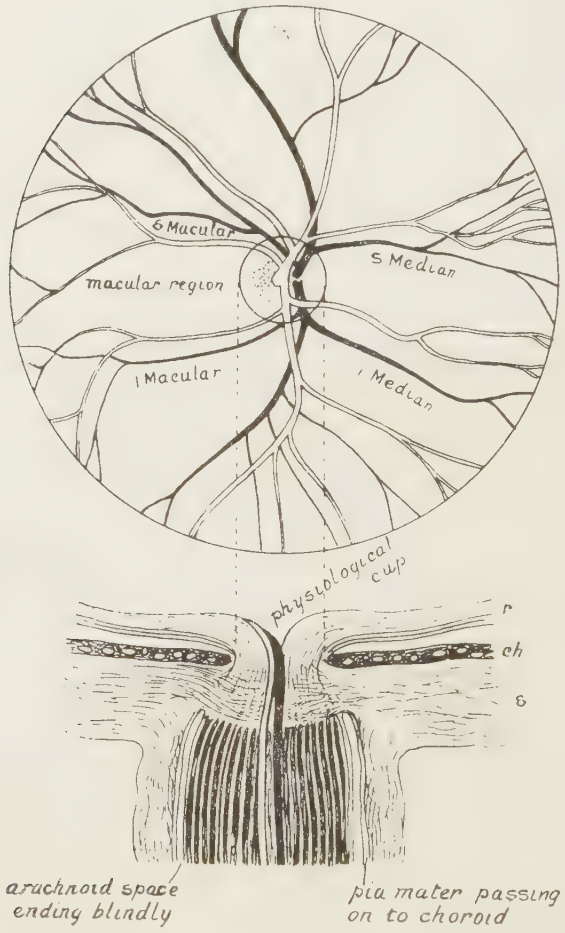


FIG. 70.
(Modified from Fuchs.)

and the axis cylinders, in bundles of varying sizes, pass through the sieve-like holes.

After emerging through these holes, and before reaching the plane of the retina, the fibres open out from one another like the petals of certain flowers, forming in this way a funnel-shaped hollow—the physiological cup.

Although of varying size, shape, and depth in different individuals, as a rule the cup on the temporal side is shallow and shelves gradually down, whereas on the nasal side it is steep.

In many cases (owing to the way the nerve-fibres separate out), the lamina cribrosa is exposed to view. Under these circumstances the cavity of the physiological cup appears, not of one uniform colour, but 'mottled,' dark-gray spots lying embedded in a steel-coloured ground. The dark-gray spots are due to the bundles of naked axis cylinders being seen as they pierce the lamina cribrosa, and as they reflect less light than the fibrous tissue of the lamina cribrosa itself, they present a darker colour.

The lamina cribrosa, consisting as it does of only the inner third of sclerotic thickness, is the weakest part of the eye capsule, and accordingly, in conditions of increased tension, is the first part to yield—'glaucomatous cup.' Moreover, the web of the lamina cribrosa being rigid, the axis cylinders of the optic nerve are very liable to become strangulated in optic neuritis.

Myopic Crescent (Fig. 78).

During the elongation of the posterior segment of the globe which takes place in myopia, the annular margin of the choroidal aperture on the side next the macula undergoes atrophy, exposing a corresponding area of the white sclerotic. Under these circumstances *a white crescent*, having its convex margin either sharply cut or ill-defined, and often edged with black, is seen on the immediate outer side of the disc; this is known as the *myopic crescent*.* (In rare cases a somewhat similar appearance may be observed in emmetropia and hypermetropia.)

In the higher grades of myopia the choroidal atrophy may be so extensive that the entire nerve-head is encircled by a zone of exposed sclerotic, and sometimes the white patch may extend irregularly for a considerable distance into the macular region (Fig. 79). When it forms a ring care must be taken not to mistake it for the boundary of the disc.

Peculiarities in Development.

The *congenital crescent* (Fig. 70*a*) is a whitish crescent, with its convexity downwards. This is a somewhat uncommon condition. Its distinguishing feature is that it occupies a situation below the disc, either directly so or a little sideways. It is generally thought to be due either to exposure of the sclerotic, the result of the fœtal cleft failing to close completely up to the margin of the disc, or else to the fact of the connective tissue of the lamina cribrosa being especially thick and dense at the lower part thereof.

Coloboma of the choroid results from the non-closure of the fœtal cleft, causing exposure of a corresponding area of the sclerotic. It occupies a situation in the lower part of the fundus, being usually wedge-shaped, with the base below and the apex upwards, but not reaching so far as the disc, and its sides pigmented. The retinal vessels usually course over the patch, but the rest of the tissue of the retina is either incompletely

* There is nearly always a myopic crescent if the myopia amount to 6 D.

developed or entirely absent. The floor of the gap is usually sunk, as the sclerotic over the area is generally thin, and in rare cases may yield to the intra-ocular tension to such an extent that an actual cyst forms, which may exceed the eye in size. It is usually associated with coloboma of the iris.

Coloboma of the Disc.—This may exist by itself or in conjunction with coloboma of the choroid. It is due to imperfect closure of the fœtal cleft at the lower part of the disc. The disc below appears enlarged, with a depressed floor, the vessels dipping down into it.

Retinal Bloodvessels.

Arteries.—With the exception of those in the disc, the retinal arteries, like those in the brain, are 'terminal.' Although their *general* distribution is more or less the same in nearly all cases, their exact course is subject to variation. As a rule, the arrangement is alike in the two eyes.

Usually the central artery issues from the disc as a single trunk and somewhat ex-centrally, then divides into a superior and inferior branch, which run respectively upwards and downwards in a more or less vertical direction, the upper giving off a *superior temporal* and *superior nasal*, and the lower an *inferior temporal* and *inferior nasal*. While the main branches are yet on the disc, each gives off a *superior* and *inferior macular* and *superior* and *inferior median*. The macular arteries skirt the yellow-spot, taking a sweep above and below it. No visible vessel can be traced into the macula itself.

Subsequently the vessels subdivide by a successive series of bifurcations, the general arrangement of the veins corresponding to that of the arteries. Both sets of vessels lie *just beneath the nerve-fibre layer*, a fact that explains the *flame-shaped* character of the typical retinal hæmorrhage. All the larger vessels are surrounded by perivascular lymphatics, which, like the vessel walls, are invisible. No capillaries have been traced by the aid of the microscope to the rod and cone layer. The fovea centralis has likewise been proved to be non-vascular.

In the small eye of hypermetropia the vessels may appear tortuous, as though they were developed for the larger emmetropic eye. For a similar reason they often run a comparatively straight course in the larger eye of myopia.

Cilio-retinal Vessels.—Occasionally independent cilio-retinal vessels, derived from the posterior ciliary, emerge from the temporal side of the disc and pass outwards towards the macula. The existence of these vessels explains the fact that sometimes in embolism of the central artery the portion of the retina supplied by them retains its vitality.

Occasionally there may be a persistent (but obliterated) hyaloid artery, consisting of a single solid thread, short or long, starting from the central artery.

Veins.—As a rule, the main vein lies completely buried in the disc, the two chief branches piercing it separately.

There is no constancy in the arrangement of the companion veins; two veins may run with one artery, or one vein with two arteries.

If a single vein accompany a single artery, the latter is generally about two-thirds the size of the former, the reason being that the artery is more distended with blood, and so presents a cylindrical, while the less distended and more flaccid vein presents a flat, tube. Broadly speaking, the diameters of the retinal veins are in inverse ratio to their number.

Comparison of Retinal Arteries with Retinal Veins.—Arteries : Lighter in colour, smaller in size, straighter in course, cylindrical in shape, branches do not anastomose ; if viewed on a plane perpendicular to observer's visual axis, they show a well-marked median light stripe. Veins : Darker in colour, usually larger, less straight in course, flattened in shape, with the median light stripe much less defined.

Pulsation in the Retinal Vessels.—*Venous pulsation* is physiological in over 70 per cent. of eyes. It occurs as a 'throbbing,' to be noticed more particularly in the main trunks as they lie on the disc.

Arterial pulsation can be produced artificially by pressure on the globe by the finger, and in rare instances may be physiological. It is occasionally found in the severer forms of anæmia, and is always present in glaucoma when intra-ocular tension is raised. It is of frequent occurrence in aortic regurgitation, being more marked the greater the hypertrophy of the left ventricle. By careful focussing, the tube can be seen to broaden and lengthen out, the former peculiarity being especially noticeable if attention be directed to a point on the vessel just before its bifurcation, and the latter if attention be directed to any spot on the artery at which there is marked curving. The pulse-wave can generally be traced a considerable distance along the course of the vessel, like the 'locomotor pulse' as seen on a surface artery, and so characteristic of 'aortic regurgitation.' (In this respect it differs from the pulsation seen in glaucoma, which is generally confined to the disc and its immediate neighbourhood.)

'Macular' or 'Yellow-spot' Region.

This is the area of maximum retinal light-sensitiveness, and closely corresponds in situation with the posterior extremity of the optic axis, being located about two disc-diameters from the outer side of the nerve-head (3 to 4 mm. external, and 1 mm. below, centre of optic disc). The term 'yellow-spot' refers to a post-mortem change, as the area never presents this colour in an ophthalmoscopic examination during life. Circular or elliptical in contour, its average diameter is about 2 mm., and its area has been estimated at about $2\frac{1}{3}$ square mm. (2·356). *It is brought into view when the patient is directed to look straight forward*, and its ophthalmoscopic appearance varies within wide limits both in different persons and under variations of illumination in the same person.

The colour is usually deeper than that of the surrounding parts (Fig. 70*a*), *but it has no well-defined boundary*, and to the uninstructed is the least conspicuous part of the fundus, being by him more often recognised by its negative than by its positive characters.

The retinal vessels sweep round; none can be seen to enter it.

The *boundary* of the macula is *slightly raised*, on account of the existence here of seven or eight additional ganglion-cell layers. From the raised border the layers gradually fine down to the centre—generally

known as the 'fovea centralis'—which is the thinnest part of the retina, consisting of but two layers, the 'cones' and 'outer-nuclear.' The macula as a whole, owing to its raised margin and depressed floor, *may be likened to a very tiny crater.*

This crater-like depression of the macula cannot be seen with the ophthalmoscope, but, owing to the extreme thinning of the retina here, it sometimes exhibits a red-brown spot, an appearance chiefly to be observed in subjects with dark complexions, and due to the subjacent pigment being especially exposed.

Ophthalmoscope Reflexes.

Certain phenomena, known as 'reflexes,' may sometimes be observed in the yellow-spot region, and in relation to the larger retinal vessels. As a rule, they are only to be met with *in children.*

They generally present a peculiar satiny shimmer, and may be of three kinds: (*a*) Macular, (*b*) foveal, (*c*) vascular.

(*a*) The *macular reflex*, when present, is generally to be seen in the form of a 'dancing halo,' or luminous ring around the fovea, shifting its position on moving the mirror. It is an inverted image of the ophthalmoscopic mirror reflected from the raised and convex rim of the macula.

(*b*) The *foveal reflex* usually takes the form of either a bright (i.) crescent or (ii.) sparkle. If the former, it may be noticed to move about in such a way that its concave side presents itself towards that part of the retina to which the eye of the observer is directed. If the observer can concentrate his gaze upon the very bottom of the pit, the crescent may sometimes be noticed to change into a tiny 'ring,' with a central glitter. The crescent is in reality an image of an arc of the *sight-hole* of the ophthalmoscope, the bottom of the foveal pit acting as a concave mirror, while the ring is an image of the circular rim of the reflector, in the former case the annular opening being excentric to the pit, and in the latter concentric to it. The sparkle, also a reflection from the concave macula, suggests the appearance of light radiating from a bull's-eye lantern, and is generally known as the *policeman's lantern reflex.*

(*c*) *Vascular reflexes* take the form of dancing reflexes in relation to the larger branches of the retinal vessels, in which connection they appear as bright, lustrous, shifting lines or bands, with a characteristic *satiny shimmer;* sometimes they assume the shape of forked lightning. They are no doubt images of those parts of the ophthalmoscopic mirror from which they receive the light.

With advancing life all these reflexes disappear or else become very faint. An important point in connection with them is that they *all shift with movements of the mirror.*

(The pathological changes which may occur in the macular region are those more especially in connection with chronic Bright's disease, central choroiditis, and senile conditions.)

Peculiarities in the Distribution of the Pigment. — As previously stated, the characteristic orange-red fundus reflex is a composite effect, the result of the mingling of the red of the blood in the choroid with the eye pigments, the colour being darkest in the neighbour-

hood of the posterior pole and becoming lighter towards the periphery, in accordance with the distribution of the pigment, which is most abundant in the region of the macula, thinning out towards the ora serrata.

Under ordinary circumstances the *vessels* in the choroid are not visible except at the periphery. Sometimes, however, and within physiological limits, the individual vessels may be seen, especially under the two following conditions :

(i.) In a very light-complexioned subject, the fundus pigment being sparse, the choroidal vessels may be noticed in the form of an anastomosing pale-red network ; while (ii.) in a very dark-complexioned subject, in whom the eye pigments are abundant, the fundus may have a tessellated appearance, being mapped out into an irregular mosaic of dull-coloured patches embedded in the network of red anastomosing choroidal vessels, caused by a special concentration of the choroidal pigment in the intervascular spaces, and a comparative absence of it over the vessels themselves (Fig. 70*a*).

Vessels of the Choroid.—The vessels of the choroid, when visible, can never be mistaken for those of the retina if the following facts are borne in mind: They freely anastomose, forming a net ; they have no light stripe ; in outline they are not so clearly marked, and are more pink in colour than the retinal vessels (Fig. 70*a*).

Tissue of the Retina.—With careful focussing by the *Direct* method, especially in the neighbourhood of the macula, a fine granular 'stippling,' or appearance suggestive of very minute grains of sand, may occasionally be observed.

This results from the hexagonal cells containing the black fucsin crystals of the pigmental layer of the retina being brought into view. Each cell measures about ·015 mm. in diameter, which, when multiplied by 15 (the magnification of the direct method), gives an apparent size of ·225 mm.

By the inexperienced observer these granules may be mistaken for a pathological state.

As before stated, the non-pigmentary portion of the normal retina being, apart from its arteries and veins, transparent, it is during life invisible by means of the ophthalmoscope, and, with the notable exception of 'opaque nerve-fibres,' any opacity present therein indicates a pathological change.

Occasionally, however, and, as a rule, only when the choroidal pigment is abundant, the actual retina can be seen in the form of a fine, softly-tinted, *pearly-gray film*, as of very delicate gauze, and although a very exceptional condition among Europeans, in the dark-complexioned races the delicate axis cylinders of the nerve-fibre layer can usually be seen radiating into the general retinal expansion.

Opaque Nerve-fibres (Fig. 70*b*).—Though the normal, living, non-pigmentary portion of the retina is transparent, the condition known as 'opaque nerve-fibres' may, as a rare congenital peculiarity, be found in one or both eyes. As before explained, the medullary sheaths ought to cease abruptly just behind the lamina cribrosa, leaving the axis cylinders naked, but in this case they resume them for some distance into the retina, giving rise to snow-white, striated, feathery-edged patches, which conceal the fundus-pigment, and in places bury the vessels. Although generally

joined to the disc, the patches may occur in the form of separate islands. They must not be mistaken for spots of 'choroidal atrophy,' which are, as a rule, clean cut, with an enveloping ring of dark pigment, and show the retinal vessels coursing over them; nor for the white patches of 'albuminuric retinitis,' being clearly distinguished from such by their flame-shaped, feathery, fringed, fibrillar or hair-like edge. In rare cases the medullary sheaths extend on to the disc, concealing a portion of it. The retina is blind over these areas. (In the rabbit the condition is a normal one.)

'Crick,' or Gunn's Dots.—This is the term applied to a rare physiological condition, in which minute, pale, or yellow-coloured dots are to be seen in the macula region, sometimes suggesting very tiny seeds. They may be very conspicuous, especially if the illumination be feeble, while, on the other hand, the light may require to fall upon them in a particular direction in order to render them visible at all.

FIG. 70*a*.—CONGENITAL CRESCENT.

The distribution of the choroidal pigment resembles the striping of a tiger's skin. The choroidal vessels are seen in the form of an anastomosing network.

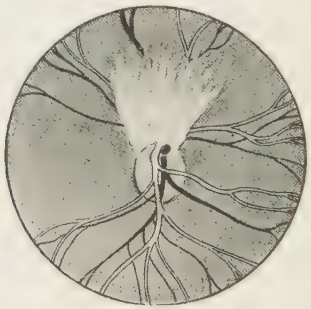


FIG. 70*b*.—OPAQUE NERVE-FIBRES.

CHAPTER VI

AMETROPIA

Emmetropia.—As previously explained, the emmetropic eye, or eye in measure, is characterized by the fact that the static refraction *unaided* can focus parallel rays on the yellow-spot — that is, the yellow-spot corresponds in situation to the posterior principal focus of the dioptric media. The term was given by Donders (*emmetros*, in due measure). 'This name expresses perfectly what we mean. The eye cannot be called a *normal* eye; for it may very easily be abnormal or morbid, and, nevertheless, it may be emmetropic' (Donders). The term emmetropia, then, merely refers to *dimensions*. This emmetropic eye, which represents the normal standard, measures from the vertex of the cornea to the yellow-spot, approximately 23 mm.; but such a perfectly adjusted optical instrument is rarely found in nature, in man perhaps in fewer than 2 per cent.

Any departure from this static refraction standard is known by the generic term of **Ametropia**, or eye out of measure. Like emmetropia, it refers strictly to the static refraction, and comprehends three distinct optical conditions:

1. Hypermetropia (H).
2. Myopia (M).
3. Astigmatism (As).

HYPERMETROPIA.

Hypermetropia (H) (*hyper*, beyond; *metron*, measure; *ops*, the eye) is that form of ametropia in which the eye is *too short* for its *static* refractive power, parallel rays being

brought to a focus, F_2, *behind* the retina, H; in other words, the retina of the hypermetropic eye in a state of rest *is in front of* the posterior principal focus, F_2, of the dioptric media. The consequence is that whereas *in emmetropia* the parallel rays coming from distant objects are focussed on the retina, E, by virtue of the static refraction alone, *in hypermetropia distant objects cannot be distinctly seen without the aid of the dynamic refraction*, the eye at rest being adapted for convergent rays (which do not exist in nature).

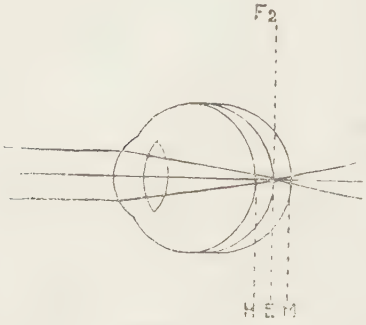


FIG. 71.

Rays coming from the retina, R, of a hypermetropic eye emerge *divergent*, and if these directions were to be continued back they would meet at a point, F, behind the eye: this point represents the *far-point*. The hypermetropic eye, therefore, has only a *virtual* far-point.

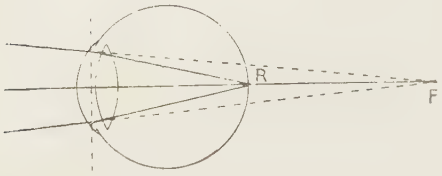


FIG. 72.—DIAGRAM OF A HYPERMETROPIC EYE SHOWING THE VIRTUAL FAR-POINT F.

From the foregoing it follows that the essential factor in hypermetropia is that the eye is *axially too short*, and that the dynamic refraction is called upon to redress the defect in the static refraction. Accordingly, *a hypermetrope can see nothing clearly without the aid of accommodation.*

Thus, as Donders puts it, 'a patient who is compelled by his hypermetropia to use some of his accommodation for *distant objects*, starts with a deficit for all the other requirements of life'—*i.e.*, for all near objects.

Etiology.—In *theory*, hypermetropia may be due to—

(*a*) The convexity of either cornea or lens being less than the normal.

(*b*) The refractive index of either cornea or lens being less than the normal.

(*c*) The visual axis being too short—*i.e.*, less than 23 mm., which is regarded as the standard measurement for the emmetropic eye.

In *practicé* it is found that the refraction of the media (with the exception of astigmatism) is a constant and fixed quantity in almost all eyes, whether emmetropic, hypermetropic, or myopic, so that (*a*) and (*b*) may be disregarded, as they but rarely occur, and (*c*) may be considered as the sole cause; hence the hypermetropia commonly met with is known as *axial*, the optic axis being so short in relation to the refractive power when the eye is at rest that parallel rays come to a focus *behind* the retina. Taking 23 mm. to be the standard emmetropic antero-posterior measurement, the hypermetropic eye would be 23 mm. $-x$. Hence accommodation is necessary to focus parallel rays on the retina; or the same result could be achieved by a convex lens placed in front of the eye.

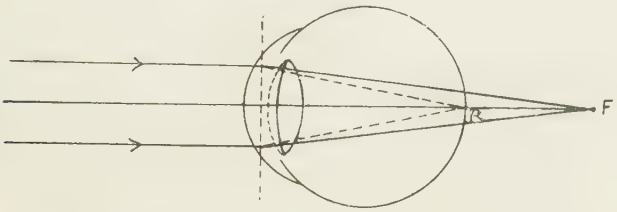


FIG. 73.

Parallel rays entering the hypermetropic eye, accommodation relaxed, are focussed at F. By the exercise of accommodation (indicated by dotted outlines) F is advanced to R.

Axial Hypermetropia.—The refraction of the eye of the newly-born is almost invariably hypermetropic, and in nearly all the lower animals a hypermetropia of about 3 D. is the rule (Landolt). The human eye at birth has a diameter of 17·5 mm. (Cunningham, 1902, A.D.), *and under normal circumstances* it continues to grow till about the age of eighteen (or full puberty), when it attains its final form, and should measure from the vertex of cornea to the yellow-spot approximately 23 mm. It may, however, attain its final form at an earlier period.

If, when growth has ceased, it has failed to acquire the

ideal measurement, the individual remains a hypermetrope; if it lengthens to it exactly, he becomes an emmetrope; while if it should exceed this limit he will be a myope. Or the matter may be expressed algebraically thus:

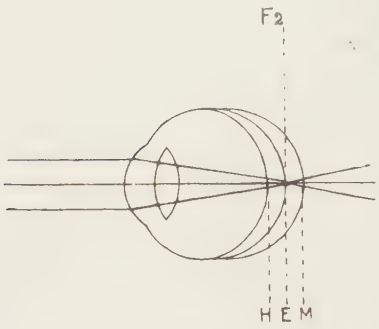


FIG. 74.

Emmetropia = 23 mm.
Hypermetropia = 23 mm. $-x$.
Myopia = 23 mm. $+x$.

Here x (the unknown quantity) represents the deficit or excess to be determined.

Accordingly, hypermetropia is always *congenital*, and may be considered, in its higher grades at least, as a condition of *under-development*, whereas myopia, on the contrary, is acquired, and may be regarded as a condition of over-development.

As the ideal antero-posterior measurement of 23 mm. is, in the human eye, very rarely attained (under 2 per cent.), *a slight degree of hypermetropia is to be looked on as the normal refractive condition of the healthy adult eye.*

Shortening of the Eye in Axial Hypermetropia.

	Shortening.	Axial Length.
Emmetropia	—	22·824 mm.
Hypermetropia ... ·5 D.	0·16 mm.	22 67 „
„ ... 1 D.	0·31 „	22·51 „
„ ... 2 D.	0·62 „	22·20 „
„ ... 3 D.	0·92 „	21·90 „
„ ... 4 D.	1·21 „	21·61 „
„ ... 5 D.	1·62 „	21·20 „
„ ... 6 D.	1·90 „	20·92 „
„ ... 7 D.	2·28 „	20·54 „
„ ... 8 D.	2·53 „	20·29 „
„ ... 9 D.	2·90 „	19·92 „
„ ...10 D.	3·25 „	19·57 „

This table, which has been taken from Landolt, has been calculated from the values of the *reduced eye*. It shows *that a* +3 D. *lens may be considered, for all practical purposes, as indicating an axial shortening of* 1 *mm.*

The existence of a low degree of hypermetropia is usually unsuspected for many years, as the defect is *masked by accommodation*, by virtue of which most low-grade hypermetropes have a distant vision of $\frac{6}{6}$ up to the age of about thirty to forty. The student must, therefore, be careful not to mistake these cases for emmetropia; he has to remember *that whilst the fact of a patient's ability to read* $\frac{6}{6}$ *excludes myopia and astigmatism from the diagnosis, it does not exclude hypermetropia.*

In the higher degrees of hypermetropia, and in many of the lower degrees after the age of forty, distant vision is below the normal standard—*i.e.*, V = less than $\frac{6}{6}$.

In those very exceptional cases of arrested eye-development known as *microphthalmos* the vision is very defective.

When in hypermetropia V equals $\frac{6}{6}$, as it often does, and we want to test whether this result is due to the action of accommodation, we place *convex* lenses in succession before the eye until we come to the *strongest* with which $\frac{6}{6}$ can still be clearly read. Supposing this to be +3 D., the amount of defect thus manifested is technically called the *manifest* hypermetropia. But this particular lens may not make evident the entire amount of the imperfection, *at least in young people*, for the accommodation may still be in action owing to an inability completely to relax the ciliary muscle; accordingly, if the eye now be brought under the influence of a mydriatic, and the ciliary muscle thereby paralyzed, it may be found that the patient requires +5 D. in order to read $\frac{6}{6}$, which shows that some degree of hypermetropia had been *latent*, the fact being that it was masked by the action of the ciliary muscle, which, from over-use, has passed into a state of spasm. Thus:

(i.) *Manifest H* = that disclosed by the strongest convex lens without the aid of a mydriatic—*e.g.*, +3 D.

(ii.) *Latent H* = that extra amount due to spasm of the ciliary muscle, and unmasked by the aid of a mydriatic—*e.g.*, +2 D.

(iii.) *Total H* = the sum of (i.)+(ii.)—*e.g.*, +5 D.

As atropine actually paralyzes the ciliary muscle, causing an amount of relaxation which is never found physiologically, an allowance of about

1 D. must be made for the loss of the so-called *tone* of the muscle, due to the action of the drug. Hence in the case assumed (ii.), +1 D. would really represent the amount of latent hypermetropia, and total +4 D.

Up to the age of about fifteen, generally half the *total H* is *latent*; but after this time the proportion which the *latent H* bears to the *manifest* tends to become less and less with advancing years, until finally, *by the age of thirty, or thereabouts, the two become merged into one—that is, all the latent H has become manifest H.*

Hypermetropia counterfeiting Myopia by Ciliary Spasm.—In some cases of hypermetropia in young people the *spasm of the ciliary muscle* may be so considerable that the parallel rays from distant objects are focussed *in front of the retina.* For example, in a hypermetrope of 4 D. there may be spasm of the ciliary muscle to the extent of 5 D., making the patient *functionally myopic* to the extent of 1 D. Thus the vision will be improved, not by convex, *but by concave, glasses. It is always a good rule to be suspicious of those cases in which the distant vision is improved by weak concave lenses,* as it not infrequently happens that such are in reality examples of hypermetropia, with spasm of the ciliary muscle, and not of myopia. Hence the importance of working out the refraction, at least in all young subjects, by the aid of a mydriatic.

SYMPTOMS—(*a*) *Objective.*—In the high grades of hypermetropia, the eye being appreciably undersized, it may appear sunken in the orbital fossa, and may present a shallow anterior chamber with a cornea distinctly smaller than normal. When the eye is turned towards the nose, the curve of the equatorial region may be noticed to be abrupt and sudden. Sometimes there is a greater range of mobility than in the normal eye.

The angle gamma (γ) is generally positive and larger than in emmetropia (*vide* p. 36). In some cases the visual line cuts the cornea so much to its nasal side that, from the fact that the centre of the cornea is turned outwards, there may be *an apparent external squint*, as the optic axes diverge although the visual lines are parallel.

(*b*) *Subjective.*—In early life, owing to the great reserve of dynamic refraction (a child of ten being endowed with + 14 D. of accommodation), there are generally no symptoms unless the degree be considerable; but by the age of thirty, and thereabouts, the amplitude of accommodation has fallen, physiologically, to +7 D., and troubles begin to manifest themselves. Thus the patient with only

a moderate defect usually finds that when he is reading the letters run into one another, and the type becomes blurred and indistinct, and that there is a tendency to eye-strain, headache, etc. All the symptoms are especially marked towards the end of the day, and they may develop suddenly after an illness. As the presbyopic epoch draws near, the print has to be held farther and farther off.

It is obvious that a hypermetrope of 3 D. would, at the age of thirty, require 3 D. of accommodation to render him emmetropic; he would thus have only 4 D. of accommodation available for near work instead of 7 D., and for sustained near vision only $\frac{2}{3}$ can be used without strain.

In the *highest degrees* of hypermetropia (from 6 D. to 10 D.) symptoms of eye-strain, headache, etc., may develop very early, even as soon as the child goes to school, so that he is unable to work long at a time without considerable discomfort.

Hypermetropia simulating Myopia.—In the very high degrees (6 D. to 10 D.) hypermetropia may counterfeit myopia, as in these cases the maximum effort of accommodation may fail to effect the proper focussing of near objects. Take, for example, a hypermetrope of twenty-five years with 8 D.; he would require practically the whole of his dynamic refraction to render his eye emmetropic for distant objects, leaving none available for near (*vide* p. 47). Under such circumstances the patient acquires the habit of holding objects (print, etc.) as near as possible to the eyes, because he thus relieves the accommodation of excessive strain by obtaining larger retinal images, though this gain, be it noted, is at the expense of some blurring, due to the diffusion circles. These cases may still further simulate myopia from the fact that the patient often contracts the habit of partially closing the eyelids in order to cut off the peripheral rays.

The hypermetropic eye has, compared with the emmetropic, much more work to do, and the following symptoms, referable to excessive use of the nerves, muscles, and blood-vessels ministering to its functions, are often to be found: conjunctival congestion, epiphora, blepharitis, photophobia, frequent blinking, headaches, neuralgia, megrim, and other allied disorders.

It is a good rule, in all cases in which any of the above-mentioned symptoms exist, to suspect the presence of hypermetropia (which may or may not coexist with astigmatism).

To sum up, all the subjective symptoms of hypermetropia

are, *per se*, to be ascribed to strain of the accommodation; for it is only when the dynamic refraction is unequal to the demands of the work imposed upon it that symptoms are present.

The existence of hypermetropia may not be discovered until the onset of, or recovery from, an illness. In all cases the symptoms are more pronounced when the general health is below par.

Post-diphtheritic paralysis is more likely to affect the ciliary muscle than any other in the body, with the exception only of the soft palate.

In connection with the complicated train of symptoms which hypermetropia may set up, the following statement of Dr. Hughlings Jackson is worthy of quotation: 'I could relate cases of hypermetropia in which the diagnosis of brain disease had been made by physicians and refuted by ophthalmic surgeons.'

Progress.—It can be affirmed as a clinical fact that high degrees of hypermetropia are relatively much commoner in children than among adults; but since the eye continues to grow till about the period of full puberty, by which time it attains its final form, they often pass into the lower grades. It may happen also that a hypermetropic eye may, during growth, become emmetropic, and even pass into the myopic. After the epoch of puberty the rule is for the congenital hypermetropia to remain stationary. It may be laid down, in fact, as a general principle that, with the exception given in the succeeding paragraph, the static refraction of any eye, whether hypermetropic, emmetropic, or myopic, rarely alters after about the age of eighteen.

Acquired Hypermetropia.—As just stated, the static refraction of the eye generally remains stationary throughout life from the period of puberty up to the age of fifty-five or sixty, after which it, as a rule, diminishes until at seventy it has become reduced to the extent of 1 D., and at eighty to perhaps 2 D. This is commonly known as *acquired* hypermetropia, and is the result of senile changes taking place in the crystalline lens and causing a diminution of its refractive index. Hence a hypermetrope of 2 D. may at the age of eighty have an actual amount of hypermetropia equal to 4 D. (*i.e.*, 2 D. of congenital hypermetropia and 2 D. of acquired hypermetropia). For the same reason a myope of 2 D. becomes an emmetrope at eighty, while the emmetrope develops into a hypermetrope. Many of these cases, however, are in the writer's opinion examples of ordinary congenital hypermetropia masked by accommodation, a function that may be retained to a later period of life than that laid down in the table (p. 47).

Tests.

Distant Test-types.—(*a*) Without a mydriatic: the strongest convex glass with which the patient can see best represents the amount of the *manifest H.* (*b*) With a mydriatic: the strongest convex glass with which the patient sees best represents the amount of the *total H.* The difference between the lenses used in (*a*) and (*b*) will indicate the *latent H.*

Examination with the Ophthalmoscope.

Distant Direct Method.—The vessels of the fundus, when visible, move in a direction *with* that of the examiner's head.

Retinoscopy.—For the results to be reliable by this method, a mydriatic must always be used. With a *concave* mirror it will be found that when it is rotated from side to side, or from above downwards, the shadow passes in the *opposite* direction. If the fundus-reflex be bright, the edge of the shadow sharp, and it move quickly, the hypermetropia is of low degree; while, on the contrary, if the reflex be dull, the edge of the shadow ill-defined, and it move slowly, the hypermetropia is of high degree.

When using a *plane* mirror, the direction of movement of the shadow is *with.*

Examination of the Inverted Image by the Indirect Method.—On gradually withdrawing the objective lens, the image of the optic disc becomes uniformly smaller; while on approximating it to the patient, the image of the disc becomes uniformly larger.

Refraction Ophthalmoscope: Direct Close Method. — The strongest + glass with which, when it is brought into position behind the sight-hole of the ophthalmoscope, the vessels adjacent to the disc can be seen with clear definition is the measure of the hypermetropia. It is important that the vessels in the immediate vicinity of the disc be fixed, as it is the refraction of the eye at, or near, the yellow-spot that is required. It is also necessary that the examiner should suspend his own accommodation, and any ametropia he may have must be allowed for. Both this and the retinoscopy

test are to be checked subjectively by the use of the distant test-types.

In looking at the fundus, the vessels often appear tortuous, as though intended for the larger emmetropic eye.

Treatment.

Treatment is not indicated by the mere fact of the existence of hypermetropia. It is only when a patient cannot read $\frac{6}{6}$, or when he suffers from symptoms of eye-strain, blurring of the type, headache, blepharitis, etc., that the use of glasses is called for.

In this connection it is to be understood that no hard-and-fast rules can be laid down, each case having to be treated on its own merits and in accordance with any special requirements or individual idiosyncrasies. It may, however, be said generally that up to the age of thirty all the *manifest H* is to be corrected, and at least half of the *latent*, as most young hypermetropes are unable to relax the accommodation completely. If *all* the *latent H* were corrected from the first, much discomfort might result from the sudden disturbance of the previously existing relation between accommodation and convergence, which functions are so intimately associated that interference with either may affect both.

Later on, however, after the eyes have become accustomed to partial correction, if symptoms still persist, all the remaining *latent H* is to be corrected, *either gradually* or *at once*, according to circumstances.

After thirty it is the general rule to correct the *total H*, as but little *latent* then remains.

In all cases in which the hypermetropia is associated with squint it is an imperative rule to prescribe the full correction* for constant wear.

Size of the Retinal Image in Hypermetropia.—In uncorrected hypermetropia the retinal image is smaller than it is in emmetropia, for the reason that, the eye being too short axially, the retina is

* By the term 'full correction' is implied the strongest + glass with which $V=\frac{6}{6}$ under atropine, making a deduction of 1 D. for the effect of the drug.

closer to the nodal point (*vide* p. 37). For distant objects, if the correcting lens be placed in the anterior focal plane of the eye (13·745 mm., or about ½ inch in front of the cornea), the size of the retinal image will be identical with that in emmetropia.

It is a principle of optics that the size of the retinal image increases the farther the convex correcting lens be removed from the anterior focal plane, and diminishes the nearer it approaches the eye. As in practice the distance of ½ inch from the cornea is too close for glasses to be worn with convenience, the retinal image will accordingly be larger in fully-corrected hypermetropia than in emmetropia.

CHAPTER VII

MYOPIA

FROM *muo*, I shut, and *ops*, the eye, in reference to the fact that many persons affected with myopia acquire the habit of half closing the eyelids when looking at objects situated beyond the *far-point*, in order to cut off the peripheral *diffusion circles*.

Myopia is that condition of **ametropia** in which the eye is too long for its static refractive power, parallel rays ($p\ p$) being brought to a focus in front of the retina at F_2, and diffusion circles formed on the retina; in other words, the retina, M, is behind the principal focus, F_2, of the dioptric system. Thus it is the antithesis of hypermetropia.

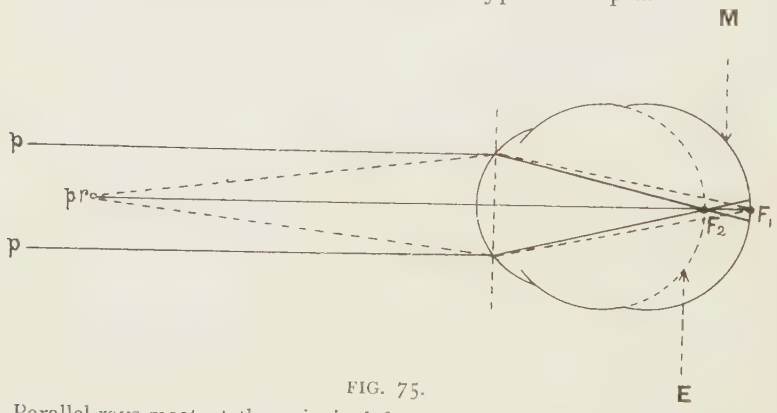


FIG. 75.

Parallel rays meet at the principal focus F_2, and, diverging, form circles of diffusion on the retina. M represents the position of the retina in myopia, and E in emmetropia.

As only *divergent* rays can come to a focus on the retina of the naked myopic eye, the *far-point*, or farthest distance at which an object can be seen distinctly, is at a limited or

finite distance (*i.e.*, less than 20 feet), *p r*, and the greater the degree of myopia, the nearer is the *far-point* to the eye.

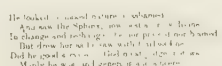
A myopic person, then, can only see distinctly an object which is at, or within, the distance of the *far-point*, and in order that an object may be clearly seen which is situated beyond the far-point, it is necessary that the rays coming from it be made as divergent as if they came from the far-point itself. This result is effected by a concave lens *placed at the anterior focus of the eye* (*vide* p. 31), and the power of the lens required indicates the degree of myopia.

FIG. 76.—DIAGRAM SHOWING HOW PARALLEL RAYS AFTER REFRACTION THROUGH THE LENS HAVE THE SAME DIVERGENCE AS IF COMING DIRECT FROM *p r*.

The concave lens is supposed to lie in the anterior focal plane of the eye —*i.e.*, 13·745 mm. in front of the vertex of cornea.

For example, if the *far-point* (*p r*) be at a distance of $\frac{1}{2}$ metre from the eye, a concave lens of −2 D. would cause the rays to enter the eye as divergent as if they came actually from *p r*, 20 inches off. In this case we should say the individual had myopia to the amount of 2 D., which is tantamount to saying that the position of the *far-point* is at 20 inches (1 metre = 40 inches, ∴ $\frac{1}{2}$ metre = 20 inches).

The *near-point*, or nearest point at which the individual can see the wires of the 'optometer,' or can read the smallest print of the *near test-type :*



is closer to the eye than in emmetropia or hypermetropia, always provided that the range of accommodation be good. (In high grades of myopia the accommodation is often weak.)

In *theory*, myopia may be due to—

(*a*) The *convexity* of either the cornea or the lens being greater than the normal.

(*b*) The *refractive index* of either the cornea or the lens being greater than the normal.

(*c*) The *visual axis* being too long (*i.e.*, more than 23 mm., which is assumed to be the measurement for the average emmetropic adult eye).

In *practice* it is found that the refraction of the media (with the exception of astigmatism) is a constant and fixed quantity in almost all eyes, whether emmetropic, hypermetropic, or myopic, so that (*a*) and (*b*) may be disregarded, as they but rarely occur; hence (*c*) may be considered as the sole cause, and the myopia commonly met with is known as axial, *the optic axis being too long* in relation to the refractive power, so that parallel rays are brought to a focus *in front of* the retina. Taking 23 mm. to be the standard antero-posterior measurement, the myopic eye would be 23 mm. $+ x$.

Every dioptre of myopia indicates a lengthening of the axis of approximately $\frac{1}{3}$ mm.

In **axial myopia**, the refractive media and nodal-point, N being the same as in emmetropia, E, and in hypermetropia, H, but the retina being further back, *the size of the retinal image in* M *is greater* (*vide* Fig. 39, p. 37). Accordingly, objects situated at or within the distance of the *far-point* are seen *magnified* as compared with the images received by these other two kinds of eye—viz., E and H. This circumstance explains the cramped handwriting of myopes.

As was pointed out in a former chapter, the refraction of healthy new-born infants is almost invariably hypermetropic. The human eye at birth has a diameter of 17·5 mm., *and under normal circumstances* it continues to grow till about the age of eighteen (or full puberty), when it attains its final form, and should measure, from the vertex of the cornea to the yellow-spot, approximately 23 mm. (The cornea reaches its full development by the age of five.) If when growth has ceased it fails to acquire this ideal standard development, the individual remains a hypermetrope; if it

lengthens to it exactly, he becomes an emmetrope; while if it should exceed this limit, he will be a myope. Or the matter may be expressed algebraically, thus:

$$\text{Emmetropia} = 23 \text{ mm.},$$
$$\text{Hypermetropia} = 23 \text{ mm.} - x,$$
$$\text{Myopia} = 23 \text{ mm.} + x,$$

where x (the unknown quantity) indicates the deficiency or excess to be determined.

From this it must follow *that myopia is acquired*, the evolution being—

From hypermetropia.
Through emmetropia.
To myopia.

Owing to the operation of causes to be subsequently discussed, the abnormal increase of the antero-posterior axis results from *a yielding of the back part of the sclerotic* to the influence of the intra-ocular pressure, whereby it expands into a *bulge* which in the higher forms of myopia may be so considerable as to constitute a *posterior staphyloma* (*staphule*, grape). The choroid and retina retreat, *pari passu*, with the recession of the sclerotic, and, as a consequence, the *yellow-spot* region comes to be displaced to a plane posterior to its normal position.

ETIOLOGY.—The essential factor in the production of myopia is—

(i.) *Over-activity of Convergence*, occasioned by a too habitual application of the eyes to near work. As, however, this *per se* would be insufficient to cause myopia, inasmuch as all people subjected to precisely the same conditions do not develop it, we assume the co-operation of an additional factor, viz.:

(ii.) *Congenital Weakness* of the posterior part of the sclerotic coat, rendering this portion liable *to bulge* under the influence of stress.

It is to be noted that prolonged convergence is altogether abnormal and artificial, for in the natural state of man it is comparatively but little required; hence it is a habit begotten of civilization.

(i.) During *convergence* the eyes do not change their position, merely the direction of their axes, since they rotate round two immovable centres—the *centres of rotation*. The muscles concerned in convergence would, acting alone, shift and render unsteady the position of the globe, unless counteracted by the simultaneous contraction of the other extra-ocular muscles; so that it may be affirmed as a general principle *that the entire group of extra-ocular muscles is more or less brought into action during convergence.** It is a law of hydrostatics that *the pressure of a fluid is transmitted equally in all directions*, and, regarding the contents of the eyeball as fluid, we must assume that under the influence of convergence these contents are subjected to a compressing force, which, under normal circumstances, is resisted by the strong, healthy sclerotic. If, however, a weak spot exist anywhere in the sclerotic, it will yield at that point, and so lead to the formation of a *bulge*. Such a weak spot at the posterior pole of the sclerotic no doubt does actually exist in those who develop myopia.

(ii.) *Congenital Predisposition.*—Inasmuch as it is not every person who develops myopia through excessive and prolonged convergence, we must take for granted the co-operation of the additional influence of *a congenital predisposition*, which would be either an *inheritance*, or what biologists term a *natural variation;* we must assume, that is, that the people who develop myopia possess a naturally weak spot at the back part of the sclerotic.

It is a cardinal principle in medicine that the causes of a disease are generally complex. 'By the *cause* of an event we mean the circumstances which must have preceded in order that the event should happen. Nor is it generally possible to say that an event has one single cause and no more. There are usually many different things, conditions, or circumstances necessary to the production of an effect, and all of them must be considered causes or necessary parts of the cause' (Jevons' 'Logic'). It is probable that other agencies besides convergence and congenital predisposition may be at work in the production of myopia. The *oblique muscles* may, owing to the nature of their attachments (which embrace the eye somewhat like a running knot), compress some of the venæ vorticosæ as they emerge from the slit-like holes in the sclerotic, thereby causing a mechanical congestion of the uveal tract (iris, ciliary processes,

* This is known as '*co-operative antagonism*' by physiologists.

and choroid), and thus possibly impairing the nutrition of the choroid (and perhaps also of the retina). If this should happen, the *anterior ciliary veins* would have to serve as safety-valves, and the fact of their carrying away more blood would explain the congested conjunctivæ so noticeable in the myope.

Furthermore, the incursion of the anterior pole of the eyeball during convergence being accompanied by a corresponding but opposite excursion of the posterior pole, there may result a pulling or dragging action of the optic nerve upon this region, the effect of which may be to weaken it, more especially if the nerve be abnormally short.

Other factors acting in conjunction with the foregoing are :

(*a*) *General.*—Sedentary occupations, confinement in badly-ventilated rooms, and other conditions that may impair the general health.

(*b*) *Local.*—The use of too fine or bad print, requiring very accurate adjustment of convergence and accommodation ; insufficient illumination —*e.g.*, reading by a dim or flickering light, necessitating very close application of the eyes (and strong convergence) in order to obtain larger retinal images, but at the expense of blurring. *Stooping* has been credited with causing a congestion of the choroid and retina, a circumstance that might affect their nutrition. Myopia is very common amongst literary people, and it is more common in Germany than in other countries. This has been ascribed to the fact that the Germans, besides being a very studious people, use an antiquated letter-type which is very trying to the eyes, requiring as it does a most delicate adjustment of accommodation and convergence. Being, moreover, to a large extent brachycephalic (or broad-headed), the eyes are far apart, and a greater strain upon convergence is the necessary consequence. Judged by the acute observation displayed in his writings, Shakespeare would appear to have been either emmetropic or very slightly hypermetropic. His extraordinary powers of accurate observation would have been quite incompatible with myopia in the pre-spectacle age, as, even if he had had it but to the degree of 2 D., his far-point would have been as near as 20 inches.

Nebulæ on the cornea, cataract, choroidal atrophy, etc., in children may cause myopia by inducing the habit of holding objects very close to the eyes in order to obtain larger retinal images, though this is always at the expense of blurring by *diffusion circles*.

PROGRESS.—Up to the age of eight myopia is extremely rare.* Ordinary myopia is generally started by over-use of the eyes at near work at an early age, the axial elongation usually commencing shortly after eight. As a rule the condition, once set up, tends, *in the absence of treatment*, to increase during the period of active body-growth—that is, from twelve to eighteen. After twenty-five it usually remains stationary. It may, however, at any time, even in the

* This statement has reference more particularly to the English, Irish, and Scots. Amongst the children of the foreign immigrants it is not uncommonly found at an earlier age.

absence of treatment, cease to progress. In other cases it becomes greater at successive stages, the periods of increase coinciding with bad states of health, or occurring when accommodation and convergence are specially strained—*e.g.*, during the close and prolonged application of the eyes in preparing for an examination.

Myopia is very liable to increase during school life from the close application of the eyes to near work, especially if under conditions of inadequate illumination, as also, perhaps, from the habit of stooping over a faultily-constructed desk.

The following case, the history of which was carefully followed, illustrates the tendency of myopia to increase from twelve to eighteen, and it also shows the influence of working for an examination. The parents were both slightly hypermetropic, and the boy was head of a public school in mathematics, and was intended for the army:

	R.	L.	
At 10 years ...	M = 0·75 D.	M = 0·50 D.	
„ 12 „ ...	M = 1·25 D.	M = 1·0 D.	
„ 14 „ ...	M = 2·50 D.	M = 2·50 D.	
„ 15 „ ...	M = 3·50 D.	M = 3·50 D.	Was specially working to enter the Royal Engineers.
„ 17 „ ...	M = 4·50 D.	M = 4·50 D.	
„ 18 „ ...	M = 6·0 D.	M = 6·0 D.	
„ 22 „ ...	M = 6·0 D.	M = 6·0 D.	

The basis of all classifications of myopia is that given by Donders, who distinguished between three kinds:

(*a*) *The Stationary*, that which does not exceed 2 D. at ten, or 2·25 D. at forty.

(*β*) *The Temporary Progressive*, that which may increase from 4 D. to 8 D. between ten and thirty.

(*γ*) *The Acutely Progressive or Malignant*, which, rapidly attaining a high degree at an early age, increases steadily and constantly.

Malignant or Acutely Progressive Myopia.

Ordinary myopia may be considered as an acquired structural change of the eye, fitting it for prolonged near work, whereby the neuro-muscular machinery of accommodation is relieved of hard work. In this sense it may be regarded as a physiological adaptation to the conditions and requirements of civilization, since a myope can see objects, assuming they be at or within the distance of his *far-point*, better than an emmetrope or hypermetrope, because, owing to the

greater distance between the nodal point and the retina, they are magnified for him (*vide* p. 37). But the elongation of the eye-ball may exceed that amount which is beneficial to the organism, increasing to as much as 10 D., 20 D., or even 30 D. (of correction); and when it thus transcends the limit of advantage and *becomes a disadvantage*, it can no longer be considered as a physiological adaptation to serve a useful purpose, but must be looked upon as actual disease. It then falls under the head of what is called *malignant myopia*, which is a distinctly pathological state of the eye. In this condition the vitreous humour is usually very fluid, often turbid, and contains numerous floating particles, a source of much annoyance. The macula (as seen with the ophthalmoscope) presents a marbled appearance, owing to disturbance of its pigment, and sometimes hæmorrhages can be observed in it as well as at other places in the fundus. The choroidal vessels are at the same time often very conspicuous, as a consequence of the thinning out of the choroidal pigment due to the extreme stretching of the eye-tunics; and finally, in these cases, *the retina is often detached.*

FIG. 77.—THE PEAR-SHAPED EYEBALL OF HIGH MYOPIA.

Diagram of a myopic eye (left) showing the 'bulge' (posterior staphyloma) in the yellow-spot area, which is seen to lie on a plane posterior to the optic disc. The dotted arc represents the original position of the posterior pole. The optic disc is tilted so that its inverted image appears as an upright oval. The eye-tunics in the region occupied by the posterior staphyloma are much thinned.

Such an eye, when removed from the orbit, shows the sclerotic to have become everywhere much thinner; at the position of the posterior staphyloma it may not be thicker than a piece of paper (*vide* p. 77).

School Myopia.

Myopia has been styled the 'melancholy privilege of the professions' and 'an accompaniment of intellectual progress.' Its existence is practically unknown amongst savage races. For all practical purposes it may be laid down as a principle that the refraction of new-born infants is invariably hypermetropic. The relation between myopia and school life has been carefully studied, more especially in Germany, where it is much more frequently met with than in this country. These observations have established the fact that children with healthy eyes, on first entering a school, have developed myopia during the period of their school life, and that the proportion increases as the scholars attain promotion into the higher classes. The Munich figures of 1889 A.D. show that of every

1,000 boys	in the	elementary class	M= 36.
,,	,,	2nd ,,	M= 49.
,,	,,	3rd ,,	M= 70.
,,	,,	4th ,,	M= 94.
,,	,,	5th ,,	M=108.
,,	,,	6th ,,	M=104.
,,	,,	7th ,,	M=108.

With the girls the numbers increased from 37 in the lowest class to 119 in the highest class.

Cohn, who was one of the first to investigate the subject, says: 'The frequency of myopia is shown by the following statistics. I noted in—

5 village schools	...	1·4 per cent. of myopia ;
20 elementary schools	...	6·7 ,, ,, ,,
2 higher schools for girls		7·7 ,, ,, ,,
2 middle schools	...	10·3 ,, ,, ,,
2 real schools ...	...	19·7 ,, ,, ,,
2 gymnasia schools	...	26·2 ,, ,, ,,

that is, out of 10,060 children, 1,004 were myopic, or 9·9 per cent.'

Priestly Smith, who examined 1,600 children attending the Board Schools in Birmingham, found 5 per cent. to be myopic; while of 350 students at a teachers' training college in the same city, 20 per cent. were myopic.

Dowling noticed that amongst all the school-children in Cincinnati 17 per cent. were myopic, but only 2 per cent. of these were under the age of nine.

Drake-Brockman, on his first experience of eye-work in India (1867 A.D.), noted but few cases of myopia; since that time, with the increase of native schools, it has become quite widespread.

An emmetropic refraction in young children should be regarded with great suspicion, more particularly if there be a family history of myopia.

Symptoms—(*a*) *Objective.*—In cases of moderate myopia, no abnormal appearances are to be noted, but in those suffering from the higher degrees of the defect the eye may appear

large, especially if it be turned inwards towards the nose, when the curve of the equatorial region is seen to be not abrupt and sudden, as in hypermetropia, but gradual—*i.e.*, egg-shaped.

As the eye in the higher grades actually is distinctly larger than normal, it has a greatly restricted range of movement, which accounts for the *bird-like* motion of the head of some myopes. The pupil is often large, and the anterior chamber deep. There may be a divergent squint from *insufficiency* of the internal recti. In myopes the back is frequently bowed forwards, with the chest concave and head bent down. A further consequence of their defective vision is that these subjects are often untidy and negligent of their appearance; dust, etc., accumulates on their clothes, and there is a general want of attention to personal details,—and naturally, since these escape their observation.

In some cases of myopia there may be *an apparent internal squint*. This arises from the fact that the cornea is cut by the visual line on its temporal side, the centre of the cornea being turned inwards; in other words, the *visual axes* pass slightly to the outer side of the *optic axes*.

(*b*) *Subjective.*—The refraction of the myopic eye being such that only divergent rays can be focussed on the retina, the *far-point* is within a distance of 20 feet. As a consequence, those objects alone can be clearly recognised which lie at or within the limit of the far-point. Objects situated beyond that distance are seen indistinctly, and the impression of them is blurred.

The distant vision of the uncorrected myope, therefore, must always be *less* than $\frac{6}{6}$.

In slight degrees of myopia, indistinctness of vision for distant objects is usually the only symptom, but in the higher degrees there may, after using the eyes for some time, be pain or discomfort, either in the eye itself, or referred to different parts of the head. Also photophobia and floating *specks* before the eyes, due to a fluid condition of the vitreous humour, may be present. If the *far-point* be very close to the eye the strain on convergence is liable to cause *muscular asthenopia*.

Small print can usually be read with ease. The hand-

writing is often cramped, the letters being magnified by the myopic eye.

Course.—In the absence of treatment the condition tends to become worse up to the age of about twenty-five or thirty, after which it ceases to progress, unless the myopia be of the malignant variety.

Tests.

Distant Test-type.—Vision in less than $\frac{6}{6}$. The *weakest* concave spherical lens which most improves vision is the register of the defect.

Note.—Take care not to mistake low degrees of myopia for *spasm of the accommodation* (*vide* p. 48).

Examination with the Ophthalmoscope.

Distant Direct Method.—The inverted picture of the fundus can usually be seen without the aid of the objective. When the examiner moves his head in any direction, the optic disc and bloodvessels move in the *opposite* direction.

Retinoscopy.—For the results to be reliable a mydriatic should be used. With the *concave* mirror the shadow moves *with*, except in myopia not exceeding 1 D., when it moves *against*. If the fundus reflex be bright, the edge of the shadow sharp, and it move quickly, the myopia is of low degree; while, on the contrary, if the reflex be dull, the edge of the shadow ill-defined, and it move slowly, the myopia is of high degree.

When using a *plane* mirror, the indications are exactly the reverse of the above.

As the concave lens which just reverses the direction of movement of the shadow, is an under-correction, −1 D. must be added to the retinoscopy result (*vide* p. 78 and 79); and since the ciliary muscle is never so relaxed naturally as it is artificially under the influence of atropine, another −·50 D. must be added.

Accordingly, if −4 D. just reverses the shadow, −5·5 D. would be the full correction. Thus:

	−4	D. just reverses the shadow
add	−1	D. for under-correction
add	− ·50	D. for effect of atropine
	5·50	D.

Examination of the Inverted Image by the Indirect Method.—On slowly withdrawing the objective lens, the image of the optic disc seems to enlarge uniformly; while on approximating it to the patient, the image of the disc seems to become uniformly smaller.

Examination of the Erect Image by the Refraction Ophthalmoscope.—The right eye is to be used for examining the right, and the left for the left. The surgeon, if not emmetropic, must neutralize his ametropia by bringing into position behind the sight-hole the necessary correcting lens, and his eye must approach as near as possible to the eye of the patient. The accommodation of both being at rest, the *weakest* concave glass with which the vessels adjacent to the *outer* side of the optic disc can be seen quite clearly defined, indicates the degree of myopia. (Be it noted that the refraction, if taken *at* the optic disc, is not to be relied on, because in many cases of myopia the yellow-spot is displaced to a plane posterior to it.)

Both this and the retinoscopy test must be checked subjectively at the distant test-types. If the patient can read, say, $\frac{6}{6}$, by means of a certain concave glass whilst the eye is fully under atropine, about ·50 D. is generally (as already stated) to be added to this result, as otherwise the particular lens chosen may be found too weak when the eye recovers from the influence of the drug and the ciliary muscle regains its tone. (It is to be remembered that myopia may be complicated by astigmatism, requiring the use of cylinders as an addition to the spheres before a good result at the distant test-types can be obtained. This condition constitutes *compound myopic astigmatism*.) (*Vide* next chapter.)

With the ophthalmoscope the following pathological appearances may also be observed:

Floating bodies in the vitreous are often present, especially in the higher grades of myopia. If they move about rapidly, the fact implies a

disorganized and very fluid vitreous. (The *normal* vitreous humour *is a tissue.*)

Owing to the fact of the sclerotic bulging behind, the retina and choroid recede *pari passu* into the concavity of the hollow, at first becoming stretched and then atrophied. This explains the phenomenon of the *myopic crescent*, which is noticed as a fawn- or whitish-coloured crescent embracing the *outer side* of the disc, and usually to be found when the myopia attains 6 D. or more. In the high grades it may be extended outwards by a succession of superadded crescents, or may appear as an irregular cone-shaped patch, with a truncated apex reaching out in the direction of the macula. If this crescent or patch be edged with pigment, it may be surmised that the myopia is stationary; whereas if the sharp black edge be wanting, the inference is that the myopia is advancing—*a very valuable indication with regard to treatment.*

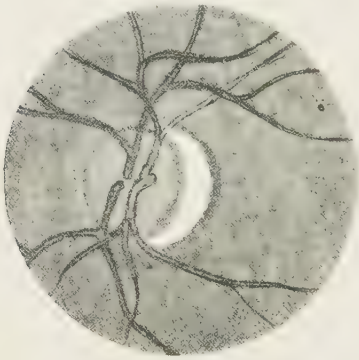


FIG. 78.—ORDINARY MYOPIC CRESCENT.

(From a case of myopia of 6 D.)

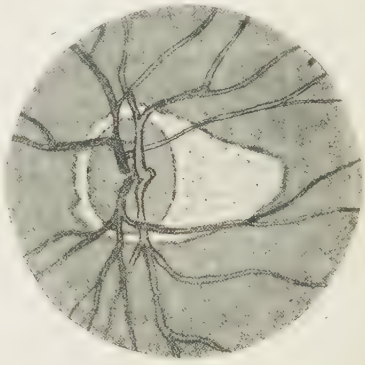


FIG. 79.—MYOPIC CRESCENT ENCIRCLING DISC AND EXTENDING INTO MACULAR REGION.

(From a case of myopia of 10 D.)

In some cases the myopic crescent may extend so that the optic disc comes to be encircled by an irregular whitish ring, which by the uninitiated may be mistaken for the actual boundary of the disc itself.

If there be marked recession of the posterior pole of the globe, the condition is known as *posterior staphyloma*, and it is a constant phenomenon of the higher grades of myopia. In these cases the disc is liable to become 'tilted' at an angle, for it then comes to lie on one side of the receding staphylomatous bulge (*vide* Fig. 77). Under these circumstances it shows when viewed in an oblique direction, a perspective foreshortening, and appears *as an ellipse, with its long axis vertical.*

In *severe forms of myopia*, such as the malignant variety, the pigment of the yellow spot becomes thinned out, owing to the stretching, and this gives to this part of the fundus a *marbled appearance.*

Retinal hæmorrhages also are common, especially in the macular region. It is in these cases, moreover, that *detachment of the retina* is apt to occur. Further, corresponding to the diseased parts of the fundus and the detached portions of the retina, there are blind spots in the field of vision (*scotomata*), and the lens may even develop cataract.

TREATMENT.

Preliminary Observations. — As previously explained, in order that the image of a *distant* object (*i.e.*, at 20 feet or beyond) may fall upon the retina of a myopic eye, the parallel rays (*p p*) coming from the object, and which in the naked myopic eye would be focussed at F_2, must be made as divergent as though coming from the far-point (*p r*), a result accomplished by a concave lens placed *in the anterior focal plane of the eye*, the focal length of which is equivalent to the distance of this far-point from the anterior focal plane.

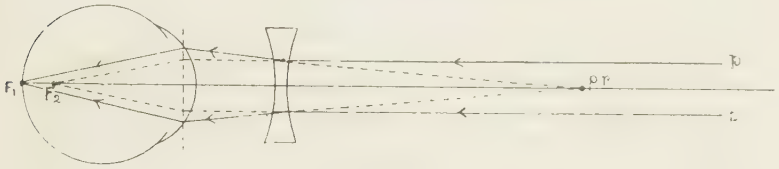


FIG. 80.

This diagram shows how parallel rays, *pp*, are focussed on the retina at F_1 by the aid of the concave lens, whereas without it such rays would be focussed at F_2.

If the fully correcting lens be placed in the anterior focal plane (13·745 mm., or about ½ inch, in front of vertex of cornea), the retinal image *is of the same size as in emmetropia.* But if the lens be placed nearer to the eye than this distance the image becomes magnified, whereas if it be placed beyond this distance it becomes minified. Hence in practice it is an important rule to have the lens in myopia as close to the eye as practicable, otherwise small objects may be rendered too diminished to be clearly perceived.

Bearing in mind the facts concerning the etiology and pathology of myopia, the indications for treatment are :

(*a*) The wearing of suitable concave spherical glasses.

(*b*) The prevention of too frequent and excessive convergence, and hence the careful restriction of the amount of eye-work.

(*c*) The provision of proper and efficient illumination.

(*d*) Strict attention to the position of the body whilst working or reading, so as to avoid stooping, etc.

(*e*) Regulation of the general health.

Glasses.—The main object in prescribing glasses is to

remove the far-point from a finite to an infinite distance (*i.e., to make the eye artificially emmetropic*), in this way relieving the strain on convergence, and at the same time enabling the patient to see distant objects clearly.

As myopia is liable to be made worse if inaccurate lenses are worn, it is of the utmost importance that the refraction be estimated with great care. Since it is more particularly *over-correction* that we wish to avoid, *it is a sound general principle that, for all young subjects at least, a mydriatic should be used, as it is only in this way that the error arising from spasm of the ciliary muscle can be eliminated* (*vide* p. 48).

No hard-and-fast rule can be laid down with regard to the strength of the lens to be used, as some myopes can, with advantage, wear their full correction for all purposes, even though the defect be great, while others have need of two pairs of glasses, one giving the full correction for distance, the other of less strength for near work.

Note.—By the expression 'full correction' is meant the weakest concave lens by means of which, with the accommodation paralyzed by atropine, the patient can see best at the distant test-types (−·50 D. being added to the result to allow for the effect of the mydriatic).

Although each case must be dealt with in accordance with particular requirements and personal idiosyncrasies, the following directions may be taken as a general guide in the selection of the glasses:

If the patient is young and the accommodation good, the eye should, *in myopia up to about* 6 D., be made artificially emmetropic by prescribing *the full correction for all purposes*. If, however, the accommodation be weak, glasses of less power must be ordered for near work, but the full correction for distance.

In myopia of more than 6 D., the full correction is to be given for distance, but a glass of lower power for near work, in order to relieve accommodation, *since in these cases the ciliary muscle is usually weak.*

Hence in myopia of more than 6 D., we must deduct from the fully-correcting lens so many dioptres as will give the patient a convenient far-point *for near work.* This is

equivalent, of course, to furnishing him with a convex lens of that number of dioptres to relieve his accommodation.

If 40 cm. (16 inches) be taken as a convenient distance at which to see distinctly near objects (print, sewing, etc.), 2·50 D. is the amount to be deducted—

$$\frac{100 \text{ cm.} = 40 \text{ inches}}{2{\cdot}50 \text{ D.}} = 16 \text{ inches.}$$

For example, suppose a case of myopia of 10 D.; we order—

$-10{\cdot}$ D. for distance,
$-\ 7{\cdot}50$ D. for near work,

which gives a reading distance of 16 inches without any necessity for accommodation.

If 33 cm. (13 inches) be the distance chosen for reading, 3 D. is the amount to be deducted. Many surgeons recommend this distance for near work.

As the correcting lens is necessarily placed *in front* of the anterior focal plane of the eye, a further advantage derived from using a lens of weaker power for near objects in high myopia is that the marked minifying effect of strong concave lenses is thereby lessened.

In high myopia (12 D. and over) visual acuteness is often much reduced by pathological changes in the fundus. In these cases a patient can rarely tolerate the full correction for distance, owing to this minifying effect. For example, a myope of 15 D. may prefer -12 D. for distance and a weaker glass still for near vision. But in all these cases, as before stated, there are personal idiosyncrasies. Accordingly, we must not seldom be content with a compromise, and order those glasses which the patient finds best suited to his general requirements and confirmed habits. Some myopes even refuse a permanent correction at all, preferring to use a lorgnette for occasional purposes. If the fundus is so diseased that visual acuteness is very defective, glasses are then of little or no use.

If there be photophobia, or the eyes be irritable, or the

glasses cause 'dazzling,' it is sometimes a good plan to order the correction in *tinted* glasses.

Note.—If there be *insufficiency of the internal recti*, it may prove useful to order prisms with their bases *inwards*, inasmuch as these relieve the strain on convergence by giving the rays of light a deflection as if they came from a greater distance.

Presbyopia in Myopes. Presbyopia is defined as that phase in the physiological decline of accommodation at which the near-point has receded to 22 cm. (9 inches), which is the focal length of a +4·5 D. lens. If myopia exist, the amount present must be deducted from the presbyopic correction required for the particular age (*vide* table, p. 140). If the myopia amount to 4·5 D., then the patient can never require presbyopic correction.

Study—Reading and Writing.

Naturally, myopes have an inclination to stoop, and the temptation to indulge in this habit must therefore be guarded against. Thus, in the case of children at school, the desks should have a convenient slope. As most cases of myopia tend, if precautions be neglected, to increase especially during the period of active school life (twelve to eighteen), and as the chief factor in their development is undue and excessive convergence, the patient is to be impressed with the importance of never bringing 'near work' closer to the eyes than 13 inches as an irreducible minimum.

The old-fashioned slate, moreover, should never be employed; for letters written on it cannot be read with the same distinctness as when inscribed on white or slightly tinted paper, the difference being at least as 3 to 4.

Vertical writing is to be preferred to slanting, being more compatible with a natural pose of the body, and at the same time lessening the liability to bend down the head. 'I abide by the opinion I expressed ten years ago—undoubtedly vertical writing is the writing of the future' (Cohn).

Long hours of study and the use of too small print are to be avoided. The general health should be attended to, and outdoor games and proper periods of rest insisted on. 'The model for all is the education of youth as practised in England, in which what are called "athletics" play a great part. To these belong swimming, rowing, riding,

archery, and a great number of games which are played in the open air and demand bodily agility ' (Fuchs).

Illumination.

(*a*) *Sunlight.*—It was pointed out by Cohn that the narrower the width of the street in which a school was located, the higher the houses opposite, and the lower the situation in the building of the class-rooms, the more numerous were the cases of myopia. His investigations bring out the prime importance of having the light good, steady, constant, and *properly directed.* It should not, however, be excesssive, for excessive light may cause photophobia. The best is that of the sun, which has been the ancestral light of man for millions of years. It should fall either from above, behind, or from the left side, so that in writing, for example, the pen will cast its shadow away from the letters. *The best position of all is where it comes from the left, behind, and somewhat above.*

In reality, for reading, writing, etc., the only light that need enter the eye is that reflected from the page, the rest of the room being in darkness ; this will afford the best *rest* for the eyes, and is a matter of importance to those liable to suffer from photophobia.

(*b*) *Artificial Light.*—The electric light is preferable to all other kinds of artificial light because it more nearly approximates in character to the light of the sun. For those who do much reading and writing, the Globe-Wernicke flexible electric lamp is to be strongly recommended, fulfilling as it does all the conditions laid down above.

Photophobia.—Black or smoked glasses may be used to lessen undue intensity of sunlight or of the electric arc, and blue glass for all ordinary artificial lights.

For reading, the print should be of good size, with the letters well-defined, and not too crowded together. Patients are to be advised not to read in trains, by firelight, or twilight.

If, in spite of these precautions, the myopia continues to

increase, the eyes must be thoroughly rested and kept under the influence of atropine for some weeks or even months, being protected at the same time by ordinary smoked or blue glasses. All near work is to be absolutely forbidden for the time being, the general health must be attended to, and a proper amount of outdoor exercise insisted on. A country life is to be recommended, and it is always desirable that people with high myopia should adopt some career not involving close application of the eyes to near work.

Removal of the Lens for High Myopia. In myopia of 15 D. or more, with a fairly healthy vitreous humour and fundus, some surgeons advocate the removal of the crystalline lens (by 'needling,' followed by extraction). Since the strength of the lens is equivalent to at least + 10 D., its removal should reduce the myopia by that amount. The results of the operation, however, are not such as to justify its performance, except in a few well-selected cases. The chief objection is the liability of highly myopic eyes *to detachment of the retina*, and when this complication is present the operation should never take place.

Emmetropia in Young Children.– If a young child, with a family history of myopia, is found to be emmetropic, it should be carefully watched and proper precautions taken ; for such a case is very liable to develop into myopia, because, as has been shown, *hypermetropia is the normal condition of the eyesight in young children.*

CHAPTER VIII

ASTIGMATISM

HITHERTO (see Emmetropia, Hypermetropia, Myopia) it has been taken for granted that the eye is symmetrical about its axis, so that all sections carried through the length of the axis geometrically correspond and have the same degree of curvature. From which it must follow that each section having the same focal length, vertical and horizontal lines lying on the same plane would be seen with equal distinctness.

In **astigmatism** there is some malformation in the shape of the eye, in consequence of which *it is not symmetrical about its axis*, so that sections carried through the axis do not geometrically correspond — *i.e.*, do not possess the same degree of curvature.

Since each section has not the same focal length, the refraction must vary in the different meridians, from which it results that the parallel rays of a homocentric pencil are not brought to a common focus; hence the name, *a*, without, *stigma*, a point. Under these circumstances, vertical and horizontal lines lying on the same plane will not be seen with equal distinctness.

Classification.

A. IRREGULAR. { (*a*) Corneal. (*b*) Lenticular.

B. REGULAR. { (i.) Corneal. (ii.) Lenticular.

A. **Irregular Astigmatism** may be due to some defect of either the cornea or lens.

(*a*) *Corneal.*—In this, the meridians of the cornea are not all of true geometrical figure, the curve of some of the meridians being flattened in places by *an ulcer* that has caused permanent destruction of tissue (like a dent on the outside of a spoon). The irregularity of the surface may also have been produced by the yielding of the infiltrated cornea to the intra-ocular pressure in *interstitial keratitis*, the bulging occurring unequally in different places. It is likewise found in *conical cornea.*

(*b*) *Lenticular.*—This results from a dislocated crystalline lens.

In irregular astigmatism visual acuteness is often much reduced, and glasses cannot improve it. The stenopaic slit or aperture is sometimes useful.

B. **Regular Astigmatism.**—Here the sweep of each individual meridian is of true geometrical figure, but all the meridians have not the same degree of curvature. An apt comparison is to the bowl of a spoon, which is more curved from side to side than from end to end, or to the surface enclosed within a circle engraven on the outside of an egg. In its minor grades, at least, but few cases of hypermetropia and myopia are without it.

The *normal* cornea not being the segment of a sphere, but of an ellipsoid with three unequal axes (*e.g.*, a Rugby football flattened sideways), it must follow that in the strict technical sense all eyes are to some extent astigmatic. In physiological optics, however, unless the condition renders V less than $\frac{6}{9}$, it is not regarded as astigmatism.

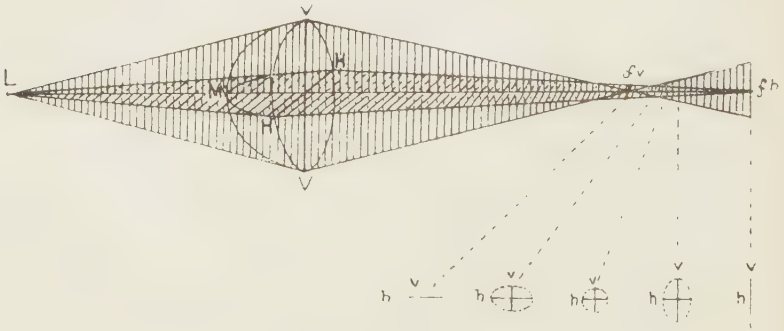


FIG. 81.—DIAGRAM ILLUSTRATING ASTIGMATISM.

Let V M V = vertical meridian of maximum, and
H M H = horizontal meridian of minimum, convexity.
L = a point from which proceeds a *homocentric pencil* of rays.
fv = focus of vertical meridian.
fh = focus of horizontal meridian.

The distance between *fv* and *fh* = *focal interval of Sturm, which denotes the degree of astigmatism.*

If a screen be interposed at successive distances from *fv* to *fh*, the pencil of rays will exhibit the various figures shown in the diagram. Be it specially noted that at *fv* the pencil is drawn out horizontally, at *fh* vertically. Inasmuch as a *line* is composed of a series of points, let L also stand for intersecting vertical and horizontal *lines;* then the vertical line will be most distinctly seen at the distance of the focus of the horizontal meridian, *fh*, while the horizontal line will be most distinctly seen at the distance of the focus of the vertical meridian, *fv*. From this it must follow that when the one line is distinctly and clearly seen it must be at the distance of its appropriate meridian, while the one at right angles to it is blurred and broadened out (p. 129), and only those lines can be clearly seen which fall upon *fv* or *fh*.

Varieties of Regular Astigmatism:

1. *Corneal.*—The meridians of the cornea are of varying degrees of curvature, and the two between which there is the greatest difference are termed the *chief* or *principal* meridians.

The *chief* meridians always intersect at right angles, and generally lie *vertically* and *horizontally*, though they may incline *obliquely*. The astigmatic formation is generally symmetrical in the two eyes.

Between the two *chief* the meridians gradually fine off, and have intermediate values, their curvature decreasing from greatest to least, and *vice versâ*.

In the majority of cases the most convex meridian is the vertical (as in the normal cornea), and the least convex the horizontal, a fact which has been ascribed to the compressing influence of the eyelids on the globe.

2. *Lenticular* astigmatism is much the rarer form, and may operate in one of two ways :

(i.) Active, or
(ii.) Passive.

(i.) *Active, or Compensatory.*—The lens is geometrically correct, but there is a corneal astigmatism which is partially or wholly neutralized by a compensatory astigmatism of the lens, effected by a localized, *meridional contraction of the ciliary muscle. Pari passu* with the advance of years, the accommodation decreases, causing a relative loss of the compensation, the result of which is that the corneal astigmatism now becomes unmasked. Under the influence of atropine the ciliary muscle is paralyzed, causing the *disappearance* of the latent, compensatory, lenticular astigmatism and the *appearance* of the corneal. Hence this form only naturally reveals itself at the advent of presbyopia.

(ii.) *Passive.*—The lens is either *tilted* or is *geometrically incorrect*, so

that the meridians are of unequal degrees of curvature, which may result thus :

(*a*) The cornea being *normal*, the tilted or the faultily-constructed lens may be the sole cause of the astigmatism ; or
(*b*) The lenticular astigmatism may either *neutralize*, or
(*c*) *Augment* the corneal astigmatism.

Speaking broadly, it may be said that 'lenticular' astigmatism so seldom occurs that in practice it may be disregarded.

Varieties of Corneal Astigmatism :

1. Simple hypermetropic.
2. Compound hypermetropic.
3. Simple myopic.
4. Compound myopic.
5. Mixed astigmatism.

1. *Simple Hypermetropic* (S H A).—The focus of one *chief* meridian is emmetropic and falls on the retina, while that of the other *chief* meridian is hypermetropic and falls behind the retina.

2. *Compound Hypermetropic* (C H A).—The eye as a whole is hypermetropic, but the cornea is less curved in one chief meridian than in the other, and, as a consequence, the foci of both *chief* meridians fall *behind* the retina, but that of the more convex in front of the other.

3. *Simple Myopic* (S M A).—The focus of one *chief* meridian is emmetropic and falls on the retina, but that of the other is myopic and falls in front of the retina.

4. *Compound Myopic* (C M A).—The eye as a whole is myopic, but the cornea is more curved in one chief meridian than in the other, as a consequence of which the foci of both *chief* meridians fall *in front* of the retina, but that of the more convex in advance of the other.

5. *Mixed Astigmatism* (H M A).—The focus of one chief meridian is hypermetropic and falls *behind*, while that of the other chief meridian is myopic and falls *in front*, of the retina, which thus lies between the two.

Causes.—*Regular astigmatism* is to be regarded as essentially a congenital condition, the result of an asymmetrical development of the cornea or lens.

In rare instances *it is acquired*, the best example being that which occurs after an *iridectomy* or *cataract* operation, when the contraction of the corneal scar-tissue causes a shortening of the meridians implicated.

SYMPTOMS.—Acuteness of vision is diminished for both *far* and *near* objects. There is usually *eye-strain*, and frequent complaint of *headache, megrim, neuralgia* and other referred head-pains, which may be occasional or more or less chronic. In addition, the patient may sometimes suffer from vague feelings of ill-health, and experience disinclination for prolonged mental or physical exertion, which the public often ascribe to 'the liver being out of order,' etc. These particular symptoms may be noticed for the first time after an illness and are liable to vary with the state of the health.

DIAGNOSIS.—The cardinal fact to be borne in mind, and upon the recognition of which both diagnosis and treatment depend, is that a pencil of rays in passing through an astigmatic medium, instead of being brought to one common focal-point, has two foci, *both of which are linear*, each corresponding to the focus of a *chief* meridian (Fig. 81).

Also, a *line* can be clearly and distinctly seen only if it stand at the distance appropriate for the focus of the meridian *at right angles to its direction;* while, on the other hand, it

Horizontal meridian, emmetropic.

will appear blurred and indistinct if it stand at the distance suited to the focus of the meridian parallel to its direction.

Vertical meridian, emmetropic.

A reference to the diagrams will make this plain. So if a patient look at an arrangement of radiating, and similar, lines, some will appear distinct and others blurred.

Tests.

Distant Test-types. — The patient should be placed at a distance of 6 metres from the type.

In the case of a hypermetrope or myope the letters can be read with accuracy and without hesitation down to a particular row, when there comes a dead stop.

With an astigmatic, on the contrary, some letters in a particular row may be read correctly, whilst others are persistently misread. Sometimes nearly the entire type is rapidly read off, the first few letters correctly, the remainder with numerous mistakes.

This is at times so marked a characteristic of the astigmatic that an inexperienced observer might be led to think (and with children more particularly) that the patient was joking.

Another characteristic sign of astigmatism to be noticed in some patients is that they incline their heads to one side when reading the type, with the unconscious purpose of adjusting the appropriate meridian to the line of type.

Again, certain small letters may be recognised while larger ones are not, a peculiarity due to the fact that particular strokes of a small letter may be suited to the focus of a *chief* meridian and appear clear, and from these the other parts of it are guessed.

We can now proceed to test with spherical glasses in the usual way in order to determine whether hypermetropia or myopia be present, and, if either, to find the strongest + or weakest − lens which will most improve vision at the *distant test-types.*

After we have eliminated this factor and reduced the condition to that of *simple myopic* or *simple hypermetropic* astigmatism *the remaining ametropia, which will represent the real astigmatism,* is to be corrected by the employment of a *cylinder,* the optical property of which is *that only the rays entering in one special plane are most refracted.*

Begin with cylinders of the same denomination as the sphere, + or − as the case may be.

The *cylinder* is to be placed in front of the selected spherical lens (if such is found to be required), and its axis

slowly rotated in different directions, as vertically, horizontally, and obliquely, the patient indicating the position in which his vision is most improved. This is repeated with successive *cylinders* until that particular one is discovered which gives the best result. If cylinders of the same denomination fail to improve vision, try cylinders of the other denomination, and proceed in the same way.

The curvature of the *cylinder*, added to that of the defective meridian, will so displace the focus of the latter as to cause it to coincide with the focus of the other *chief* meridian, thus making the eye artificially emmetropic.

A *double spectacle-frame* should be used, the *spherical* lens being placed next the eye with the *cylinder in front*, an arrangement which allows of the easy rotation of the latter to the required position.

Mixed Astigmatism.—In the testing of this condition the + or − sphere which gives the best results is to be found, after which *cylinders* in succession are to be placed in the spectacle-frame and rotated into different positions until that particular one is discovered which most improves vision. With a + sphere a − cylinder would be required, and *vice versâ*.

Examination by the Ophthalmoscope.

Retinoscopy is an invaluable aid in the determination of astigmatism, as it saves an immense amount of trouble, especially in the case of young children. One of its great advantages is that the position of the chief meridians can be decided at once, and in this way we are put on the right track from the first. The results are, of course, only *approximately* correct, and in all cases where subjective examination is possible they must be checked by the distant test-types.

Axiom I.—The apparent movement of the shadow is always in a direction at right angles to its edge.

Axiom II.—In whichever way the mirror be rotated, the apparent movement of the shadow is always in the line of the nearest *chief* meridian.

The *direction of the movement* of the shadows and the *greater distinctness* or *quicker* movement of either should be noted. Also whether they move in the *vertical* and *horizontal* or in some *intermediate meridians*. Each chief meridian should

be corrected separately, just as hypermetropia or myopia would be corrected in any simple case by placing spherical lenses in succession in the trial-frame until that one is found which *just reverses* the shadow. The difference of refraction between the two chief meridians represents the degree of astigmatism. −1 D. is to be added to the result just as in hypermetropia and myopia, and allowance must be made for the effect of the atropine (*vide* p. 78).

In the following examples the lens given is that *which just reverses* the direction of the shadow, and after adding −1 D. and allowing for the effect of the atropine the result will express the *theoretical* correction. For the *practical* correction the patient is to be examined at the distant test-types, when slight changes will perhaps have to be made in the strength of the glasses or the inclination of the axis of the cylinders. The whole of the astigmatism is to be fully corrected in all instances, and in this way the condition is reduced to one of *simple hypermetropia* or of *simple myopia*, as the case may be; any alterations in the spherical glasses must be made in accordance with the rules laid down in the sections on the treatment of these forms of ametropia.

Adding −1 D.,
allowing −1 D. for atropine,
the theoretical correction would be—
+1 D. spherical
+1 D. cylindrical, axis vertical

Adding −1 D.,
allowing − ·50 D. for atropine,
the theoretical correction would be—
−3·50 D. spherical
−1 D. cylindrical, axis vertical

Adding −1 D.,
allowing − ·50 D. for the M m'd'n and
−1 D. for the H m'd'n,
the theoretical correction would be—
+1 D. spherical
−4·50 D. cylindrical, axis horizontal

because +1 D. spherical would correct the hypermetropic meridian, but would make the myopic meridian yet more myopic to the extent of 1 D.

Note.—Some surgeons *always avoid the use of horizontal cylinders*, as these are inconvenient for reading, and would, in the case given above, prescribe—

−3·50 D. spherical
+4·50 D. cylindrical, axis vertical

which gives the same correction as the previous glass—*i.e.*, −3·5 D. in the vertical and +1 D. in the horizontal meridian.

Indirect Method.—The inverted image of the *optic disc* is oval, the elongation appearing in the meridian *of least convexity;* thus, if it be elongated in a horizontal direction it shows the vertical meridian to be of maximum, and the horizontal of minimum, convexity. On withdrawing the *objective* from the eye under examination, the *disc* becomes relatively larger in the direction of the maximum, and relatively smaller in the direction of the minimum meridian, a phenomenon especially marked in *mixed* astigmatism.

Diagnosis by the Direct Method.—The erect image of the *disc* is oval, and the elongation corresponds to the meridian of *maximum convexity*.

Take as the *test-lines* the vessels running from the disc, and remember that the spherical lens which, placed in position behind the sight-hole, brings one set of vessels into focus while the opposite set is blurred, is the correction of the meridian at right angles to it.

Accordingly, if with a certain glass the *vertical vessels* running from the disc are seen clearly and distinctly, it is proved that the refraction of the *horizontal meridian* has been settled. Having determined this, the next step is to find the glass which will render the *horizontal vessels* clear and distinct, the result denoting the correction for the *vertical meridian*. The difference between the two glasses indicates the amount of astigmatism.

If the *chief* meridians are not vertical and horizontal but fall obliquely, the glass which renders clear and distinct the

vessels running slantwise will be the correction for the meridian at right angles to their direction; and *vice versâ*.

In the estimation of the refraction by the *direct method* the distance between the observer's eye and that of the patient should always be as short as practicable (if possible, 1 inch), the strength of a convex lens being increased, and that of a concave lens diminished, by increasing the distance from the eye.

It is to be borne in mind that the refraction of an eye is not the same in all parts of the fundus; it may be myopic at the macula and hypermetropic towards the periphery. Hence it is of great importance *to apply this test to the vessels in the immediate vicinity of the disc on the macular side*.

If the *metal disc with stenopaic* (*stenos*, narrow, *ope*, hole) *slit* be placed in front of the eye and slowly rotated, it will be found that the patient can see best when the slit occupies one particular position, which position is that of a *chief* meridian. This being established, + or − spheres are then placed in succession in front of the slit until the one affording the best possible vision is found, the lens giving such result being the correction for the meridian in question.

By rotating the disc until the slit is at right angles to its former position the direction of the other *chief* meridian may be found and its error corrected in a similar way. Example:

With slit vertical ... ... $V=\frac{6}{6}$.
With slit horizontal ... ... $V=\frac{6}{18}$ c + 1 D. $=\frac{6}{6}$.

The case is one of simple hypermetropic astigmatism of + 1 D. This method is equivalent to making spheres serve the purpose of cylinders in the investigation.

Whichever manner of procedure be adopted for the investigation of astigmatism, it should always be verified at the distant test-types, which, except in the case of children unable to read, should be regarded as the ultimate and confirmatory test of this defect of vision, the other methods merely serving as preliminaries thereto.

Treatment.

Having applied one or several of these different tests, the result is to be checked by trying the patient with the appropriate glasses at the *distant test-types*, at the same time making any necessary changes that may be required to raise V up to $\frac{6}{6}$.

$\frac{6}{6}$ is to be regarded as the *normal standard*, but we

often have to be content with a less satisfactory result, and, in *mixed* astigmatism more especially, it may not be possible to improve vision to more than $\frac{6}{18}$.

A *cylindrical* lens is one whose refracting power is at a maximum in the meridian at right angles to the axis, and zero in the meridian parallel to the axis, the rays passing through which undergo no deviation, while the intermediate meridians have intermediate values — *e.g.*, +4 D. cylinder = 4 D. at right angles to axis = 0 at axis = 2 D. in the meridian of 45° (*vide* p. 19).

The cylindrical lens is placed in front of the eye so that the direction of its curvature coincides with the direction of the faulty curvature.

FIG. 82.—DIAGRAM SHOWING FOCI OF A LENS (AS REPRESENTING AN ASTIGMATIC EYE) HAVING TWO MERIDIANS OF DIFFERENT CURVATURE IN PLANES AT RIGHT ANGLES, THE VERTICAL BEING MORE CONVEX THAN THE HORIZONTAL.

(i.) If the retina be in the plane of *fv*, this eye is emmetropic for the vertical plane and hypermetropic for the horizontal plane (*i.e.*, 'S H A'). (ii.) If the retina be at *fh*, it is emmetropic for the horizontal and myopic for the vertical plane (*i.e.*, 'S M A'). (iii.) If the retina be at K, the eye is myopic for the vertical and hypermetropic for the horizontal plane (*i.e.*, 'mixed astigmatism').

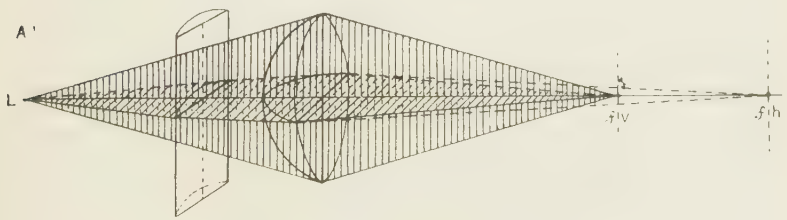


FIG. 83.

This is Case A i., with the *simple hypermetropic astigmatism* (S H A) corrected by a *convex* cylinder, which, by displacing *fh* forward, makes the eye emmetropic (retina at *fv*).

FIG. 84.

This is Case A ii., with the *simple myopic astigmatism* ('S M A') corrected by a *concave* cylinder, which by displacing *fv* back to *fh*, makes the eye emmetropic (retina at *fh*).

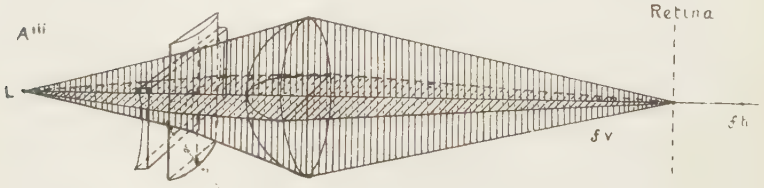


FIG. 85.

This is Case A iii., showing mixed astigmatism, where the focus of one chief meridian lies in front of the retina and the other behind the retina. The focus of the hypermetropic horizontal meridian, *fh*, is advanced to the retina by the convex cylinder, and the focus of the myopic vertical meridian, *fv*, is displaced back to the retina by the concave cylinder, the eye being thereby rendered emmetropic.

The *axis* of the lens, then, must be parallel to the normal meridian in order that the rays passing through may undergo no deviation, whilst the rays entering at right angles to the axis undergo just that degree of deviation sufficient to neutralize the defect in the abnormal meridian.

Example.—In S H A the axis of the correcting *cylinder* must lie parallel to the meridian of maximum refraction, whereas in S M A its axis must lie parallel to the meridian of minimum refraction. The same remarks apply to C.H.A. and C M A.

In ordering glasses for the correction of astigmatism, there are three possible combinations, any one of which may be selected:

1. Sphere with + cylinder.
2. Sphere with − cylinder.
3. Crossed cylinders.

Transposition Rule.—Any particular *cylinder* may be re-

placed by a sphere of equivalent power, united with a cylinder of equal but opposite power, on an axis at right angles.

For example: Patient has H amounting to +4 D. in the vertical, and to +6 D. in the horizontal meridian, and the correction may be prescribed in either of the three following ways:

1. +4 D. spherical +2 D. cylinder axis, vertical (90°).
2. +6 D. spherical −2 D. cylinder axis, horizontal (180°).
3. +4 D. cylinder axis 180° +6 D. cylinder axis (90°).

Of the sphero-cylinders, the most satisfactory is that which has the smallest numerical curvature, as the deeper the curvature the heavier the lens, and where possible it is advisable to obtain a periscopic effect—that is, the lens as a whole should have a similar outward curvature to that of the eye; this can be secured most easily in such cases as require a + sphere outside and − cylinder inside, and + cylinder outside and − sphere inside.

Of the combinations, the one usually chosen is (1), the general rule being, in *compound astigmatism*, to order the *spherical* lens which corrects the meridian of least curvature (*i.e.*, +4 D. in the case cited), and then to combine with this the cylinder, convex or concave according to circumstances, whose power represents the difference between the two chief meridians—*i.e.*, +2 D. cylindrical, axis vertical in the same case.

In mixed astigmatism the general rule is to order the *spherical* lens *convex*, and the *cylindrical* lens (which will represent the difference in refraction between the two *chief* meridians) *concave*. For example, if the vertical meridian = −2 D. and the horizontal meridian = +1 D., the advisable combination would be—

+1 D. spherical
−3 D. cylindrical, axis horizontal.

If, on the other hand, it is decided to reverse matters, the combination will be—

−2 D. spherical
+3 D. cylindrical, axis vertical.

Crossed cylinders are very difficult to grind with scientific precision, are liable to cause troublesome *spherical aberration*, and are very expensive, for all of which reasons they are seldom or never ordered.

Wearing Glasses for Astigmatism.—In all cases the *full correction of the astigmatism* is to be ordered, and the cylinders should be *always worn;* to this rule there is no exception. The spheres are ordered in accordance with the laws governing the treatment of H and M. There may be a *period of adaptation*, lasting from one to twelve weeks, or even more (especially when strong cylinders are required), during which *discomfort* and *blurring* may be complained of; and the patient must be cautioned that immediate benefit is not always possible, but that a certain time must elapse before the full advantage will be experienced. If this warning is not given, the glasses are liable to be discarded and the surgeon perhaps blamed for incompetence.

In high degrees, *a lengthened period of adaptation to the cylinders may be necessary*, and so the improvement effected by the use of proper lenses may at first be but slight after the effect of the atropine has worn off, but by perseverance in their use a good result is to be anticipated in course of time.

Eye-strain, headache, megrim, giddiness, etc., are often relieved or cured by correcting even such a low degree of astigmatism as ·25 D. When such symptoms are present the continual use of the glasses during the daytime is specially of the utmost importance (*vide* 'Headache and other Cephalic Sensations,' by Dr. H. Campbell). In young subjects the refractive error should always be worked out under atropine. It is often wise to continue to keep the eye under the influence of the mydriatic for some time after the glasses are worn, for by so doing it may more readily become accustomed to the correction, and the period of adaptation be correspondingly shortened.

If, although a patient can read $\frac{6}{6}$, the letters appear blacker and better defined by the aid of ·25 D. cylinder, it is advisable to prescribe this low grade of correction for constant use should symptoms of eye-strain, headache, etc., be present.

Differential Meridional Contraction of the Ciliary Muscle.—Although denied by the physiologists, there is little doubt that in many

forms of astigmatism the accommodation may act entirely differently from what happens in other forms of ametropia or emmetropia, as the results obtained in working out the refraction with and without atropine are so often anomalous. For example, a case of a child, aged ten, came recently under observation presenting the following peculiarities:

R.E. +5 D. cyl. axis vert. = $\frac{6}{6}$ L.E. +5 D. cyl. axis vert. = $\frac{6}{12}$	Under atropine.
R.E. +2 D. cyl. axis vert. = $\frac{6}{5}$ L.E. +2 D. cyl. axis vert. = $\frac{6}{18}$	Fourteen days after the atropine was stopped. Higher cylinders reduced the visual acuteness.

From this it would appear that the accommodation may be exerted *more in some meridians than in others*. The phenomenon is, when present, generally found in *hypermetropic* astigmatism. (Hess is a strong opponent to this theory, and for his views see end of chapter.)

Hence it may be laid down as a general principle that in all cases of astigmatism, in young people at least, *the refraction should be worked out under atropine.*

In the treatment of astigmatism it is of the greatest possible importance that the spectacles should fit accurately. The lenses should be on the same plane and horizontal level, and properly centred with respect to the pupils, as the least deviation of the axis of the *cylinder*, caused by tilting, depression, or displacement of the glass, may possibly occasion much indistinctness of vision, and perhaps a complete failure to achieve the special object for which they were prescribed—*e.g.*, the relief of eye-strain, headache, etc. When not worn they should be carefully put away and protected from damage, as any injury done to them, however apparently trivial, such as even slight twisting, etc., of the frames, is liable to impair or nullify the benefit otherwise to be derived from their use.

Hess (*Arch. f. Ophth.*, 1896, Bd. xlii., Abth. 2, S. 80) disagrees with the generally accepted theory that astigmatics accommodate for one or other of their linear foci. He 'finds that this is not the case, but that accommodation normally occurs for that point in the interfocal region where the focus is approximately circular. Using a photographic apparatus rendered astigmatic by a cylindrical lens, Hess found that the clearest image occurred at the circular focus; and careful observations of the eyes of astigmatics showed that when they saw most distinctly their refraction was adjusted approximately to the circular focus. The variations in astigmatic vision, which have been ascribed to meridional accommodation, may very well have been due to variations in the adjustment of the eye to different parts of the interfocal region' (Schafer).

CHAPTER IX

PRESBYOPIA

As has been explained, **ametropia** has reference to the *static* refraction of the eye; on the other hand, **presbyopia** refers to *dynamic* refraction alone. Donders was the first to establish on scientific principles the fact that, whilst the *static* refraction remains stationary till the age of fifty-five or sixty, the *dynamic* refraction declines at a uniform rate from the age of ten up to seventy, by which time it has entirely disappeared; and, *pari passu* with this declension, the *near-point* recedes further and further from the eye, until it ultimately coincides with the *far-point*.

Table showing the Amplitude of Accommodation at different Ages in the Emmetropic Eye.

Years.	Near-point.	Amplitude of Accommodation.	
10	7 cm.	14 D.	
15	8 „	12 D.	
20	10 „	10 D.	
25	12 „	8·5 D.	
30	14 „	7 D.	
35	18 „	5·5 D.	
40	22 „	4·5 D.	Presbyopic Correction.
45	28 „	3·5 D. $\bar{c}+1$	D =4·5 D.
50	40 „	2·5 D. $\bar{c}+2$	D.=4·5 D.
55	55 „	1·5 D. $\bar{c}+3$	D.=4·5 D.
60	100 „	1·0 D. $\bar{c}+3·50$	D.=4·5 D.
65	200 „	0·5 D. $\bar{c}+4$	D.=4·5 D.
70	400 „	0·25 D. $\bar{c}+4·25$	D.=4·5 D.
75	infinity	0· $\bar{c}+4·5$	D.=4·5 D.

The punctum proximum (pp) is found by dividing 100 cm., or 40 inches, by the dioptres of accommodation, when the quotient gives the near-point in centimetres or inches.

It will be seen by reference to the table, which applies strictly to the emmetropic eye, that at forty the *near-point* is 22 cm. off (9 inches), 4·5 D. of accommodation being then available. Since, however, the whole of the *dynamic refraction* cannot be employed *for sustained near vision* (inasmuch as at least $\frac{1}{3}$ must be held in reserve, as previously explained,

p. 48),* it follows that up to the age of forty an emmetrope should be able to read, without discomfort or strain, at a distance of 13 inches—

$$(4{\cdot}5\text{ D.} - 1{\cdot}5\text{ D.} = 3\text{ D.}\quad \frac{1\text{ m.} = 100\text{ cm.} = 40\text{ inches}}{3\text{ D.}}\quad 33\text{ cm.} = 13\text{ inches.}$$

By the time the age of forty-five is reached, however, he will have at his disposal, *for sustained near vision*, only 2·25 D. (3·5 D. − 1·25 D. = 2·25 D.), *giving a reading distance of* 18 *inches*, and as the retinal image becomes smaller and smaller the further from the eye the object is carried, it is found in practice that small print cannot conveniently be read at this distance without assistance from glasses.

Presbyopia (*presbus*, old; *ops*, the eye) may be defined as that phase in the normal decline of accommodation in which

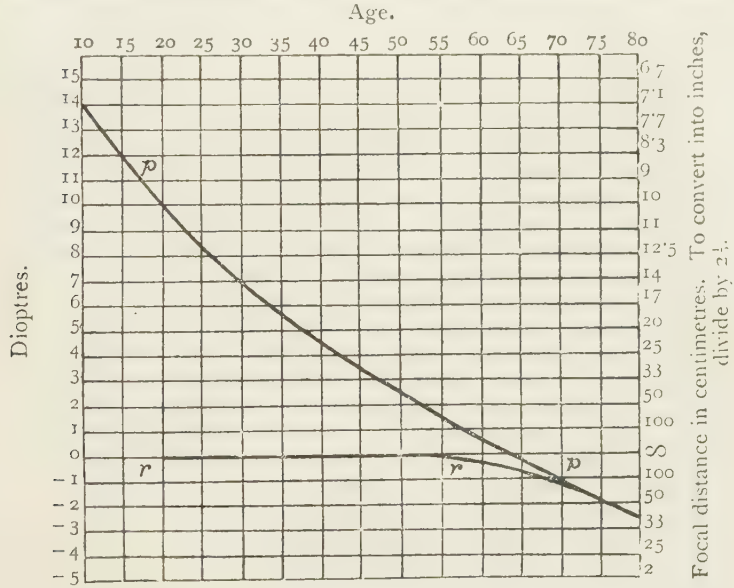


FIG. 86.—POWER OF ACCOMMODATION AT DIFFERENT AGES (DONDERS).

The horizontal curve, *r r*, shows the static refraction of the eye, and how it begins to decline at the age of fifty-five years.

The vertical curve, *p p*, shows the uniform declination of the dynamic refraction, which begins at about the age of ten years.

an individual can no longer command 4·5 D. of dynamic refraction—that is, when the *near-point* has receded beyond 22 cm. (9 inches).

* Allowance must be made for idiosyncrasy. Many people can only employ with comfort *half* of their accommodation for *sustained* near vision.

From this definition it follows that it begins after the age of forty *in emmetropia*, and that the correction, in principle, should accord with that given in the fourth row of the table (p. 140) in order to bring the *near-point* to 22 cm. But it is to be clearly understood that this is not to be rigidly followed in all instances; it is rather to be regarded *as a standard upon which to base our calculations*. Presbyopia, then, is a purely *physiological condition*, and, as Donders remarks, 'is no more an anomaly than are gray hairs or wrinkling of the skin.'

As the term is a somewhat arbitrary one, each case of presbyopia must be considered as constituting a law to itself, and treated in accordance with the particular conditions that may obtain, *the one desideratum being to give a near-point for a distance corresponding to that required—i.e.*, for reading, writing, working, etc. For example, it will not suit a person accustomed all his life to use his eyes for *near-work* at 20 inches to oblige him to read at 9 inches, for this will entail an effort of convergence that may cause *strain*, besides the discomfort likely to arise from suddenly disturbing the previously existing relation between accommodation and convergence, two functions which are so intimately associated.

Again, in the case, say, of a carpenter, aged sixty, accustomed to perform his work at a distance of from 24 to 30 inches, it will not do to compel him to have it at only 11 inches, as we should if we strictly adhered to the table and ordered +3·5 D.

We must proceed, then, on the principle of prescribing glasses *which bring the near-point to a position demanded by the work in question*, in all cases consulting the convenience, occupation, and habits of the patient.

Let it be repeated that the foregoing statements are made with reference to the *emmetropic* eye. An *ametropic* eye must be made emmetropic (*i.e.*, by lenses) before the correction for presbyopia can be applied.

Rule.—In hypermetropia* we *add* the presbyopic lens to that which corrects the hypermetropia; in myopia we *deduct it* from that correcting the myopia—in other words, take the

* The existence of any *acquired hypermetropia* must also be taken into account (*vide* p. 102).

algebraic sum. Thus, in *hypermetropia* of 2 D. at the age of fifty-five years, the correcting presbyopic lens would be +5 D. (H = +2 D., P = +3 D.); while in *myopia* of −2 D. the correcting presbyopic lens would be +1 D. (M = −2 D., P = +3 D.).

The same remarks hold good in astigmatism, so that in all cases the eye, if not naturally emmetropic, *must be made so artificially* before presbyopic lenses can be prescribed.

In some cases of hypermetropia the presbyopic correction may have to be commenced before the age of forty-five. Inasmuch as uncorrected hypermetropes require to accommodate for *far*, as well as *near*, objects, accommodation may *prematurely decline* as the result of overwork, so that instead of a person of forty possessing +4·5 D. of accommodation, as represented in the table, he may have only 3·5 D. at that age, or even less.

An *uncorrected* hypermetrope of 3 D. would really be presbyopic at thirty, for at that age he would normally possess but 7 D. of accommodation, 3 D. of which would be required to render him emmetropic, leaving only 4 D. of accommodation for near objects. From this illustration it will be understood that the term *presbyopia* is a quite arbitrary one, and refers strictly to emmetropia, which is the rarest refractive state of the eye.

In myopia the period for beginning the presbyopic correction has to be deferred.

In myopes the presbyopia manifests itself at a later period than forty-five years, and may not come on at all—for example, in a myope with −4·5 D. or more.

The onset of presbyopia occasionally varies even in emmetropes.

In emmetropia occasional departures from the standard table may be met with in either one of two ways. Thus, it may occur (*a*) prematurely, the presbyopia manifesting itself before the age of forty-five; or (*b*) the onset may be deferred, in which cases the presbyopic correction may be (*a*) anticipated or (*b*) postponed.

SUMMARY OF TREATMENT.—The *general principle* of treatment is to give the patient a near-point, which the normal eye can command at the age of forty—that is, 22 cm. (9 inches). The convex glasses *theoretically* indicated are those given in the fourth row of the table. It is usual to begin the correction of presbyopia at the age of forty-five, by which time a +1 D. is generally necessary, In all conditions of *ametropia* the eyes must be made emmetropic by the aid of the suitable lenses, the strength of which must be *added* to the presbyopic correction, an arrangement which has the effect of increasing the strength of those demanded for H c̄ P, and decreasing the strength of those demanded for M c̄ P.

In *practice* we often have to order rather less than the full correction, and in all cases the glasses prescribed must have reference to the particular purpose for which they are required, with due consideration of the convenience and habits of the patient. Sometimes *a period of adaptation* elapses before the full benefit is derived from their use, *during which the internal recti are educated to their altered function of convergence.*

It is of great importance that the glasses fit accurately—that is, their optical centres must coincide with the lines of fixation.

CHAPTER X

ANISOMETROPIA

This name is applied to that state of the sight in which the refraction of the two eyes differs (*anisos*, unequal; *metron*, a measure; *ops*, the eye). As a small degree of inequality is not uncommon, the term is restricted in practice to those cases in which the difference is pronounced. Anisometropia is the usual state of the eyes in concomitant squint. All possible combinations of it may be met with, but the importance of the condition depends upon the degree of it present. Binocular vision is possible in anisometropia only when it is present in moderate amount (up to about 1·50 D. to 2 D.); whereas, if it is in excess of this, monocular vision with the eye possessing the least refractive error is the rule, the reason being *that the retinal images, when too dissimilar, cannot be properly fused.*

Sometimes one eye is used for 'distant' and the other for 'near' objects.

It may be that a patient is not aware that he habitually suppresses the vision of one eye until such time as he happens to close the 'working' one separately from its fellow.

It is noteworthy that anisometropia is rarely, if ever, neutralized by any compensatory accommodative effort.

Great care and discrimination are required in prescribing the glasses. As a rule, the younger the patient the more favourable the result to be anticipated. Each case is a law to itself, and though no hard-and-fast rule can be laid down, the following directions may be offered as guiding principles:

If visual acuteness be good in both eyes, and the difference in refraction be not more than from 1·50 D. to 2 D., each eye

is to be allowed the full correction, *a fact of importance if squint be present*. In exceptional instances a difference of as much as 3 D. or 4 D. can be tolerated. If the anisometropia amount to more than from 1·50 D. to 2 D., full correction for both eyes is to be regarded as impracticable, owing to the inability to fuse the two unequal retinal images. It is to be remembered that convex glasses (as they have to be worn) increase, and concave glasses decrease, the apparent magnitude of objects, and hence, when the disparity in size between the retinal images exceeds a certain limit, ocular discomfort, diplopia, giddiness, etc., would ensue as a consequence of any correction ignoring the incapacity for binocular vision.

Under these circumstances, we must be content to give the proper correction for the 'working' eye, and deal with the other in either of the following ways:

(*a*) Order the full correcting cylinder for any astigmatism that may be present, coupling it with a sphere of equal value to that prescribed for the better eye; or,

(*b*) Order a plane glass.

If the 'non-working' eye be amblyopic, it is sometimes well to attempt the education of it by instructing the patient to practise using it, the other eye being meantime excluded from use.

CHAPTER XI

POSITION OF SPECTACLE GLASSES

(*a*) Theory.

THE **Myopic Eye**, being axially too long, is naturally adapted for divergent rays when the accommodation is relaxed. The remote point is at some finite distance, and the less this distance is the greater the degree of myopia.

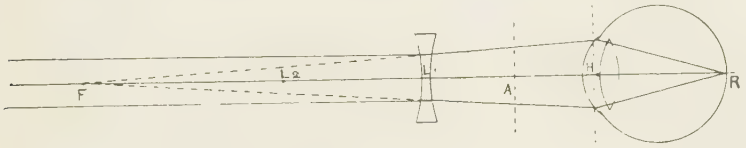


FIG. 87.

Let F (Fig. 87) represent the far-point of a myopic eye. Rays divergent from this point are exactly focussed at the point R on the retina. Now, in order to render the eye artificially emmetropic—*i.e.*, to remove its far-point to infinity, a concave lens must be placed in front of the eye, of such strength as to give to parallel rays the same degree of divergence that rays coming from F would have without the lens.

Suppose the lens placed at L_1 then its focal length must be equal to the distance L_1 F. If placed further away from the eye, as at L_2, then a focal length equal to L_2F will suffice, and if nearer than L_1 a correspondingly greater focal length.

When a lens is placed in the anterior focal plane of the eye 14 mm. in front of cornea, the retinal image of an object is the same size as in an emmetropic eye, and a concave lens in any other position has a magnifying or minifying effect, according as it is nearer or further away; hence it is the aim of the practitioner to place the lens as nearly as possible at A, the anterior focal plane. If, for example, the far-point is 264 mm. in front of the eye, the lens required must have a focal length of 264 − 14 = 250 mm.—that is, a − 4 D. lens $\left(\frac{1 \text{ metre}}{250 \text{ mm.}} = 4\right)$.

The **Hypermetropic eye**, being axially too short, is naturally adapted, when accommodation is relaxed, for convergent rays. The re-

mote point is farther off than infinity, so to speak—*i.e.*, it is virtually behind the eye.

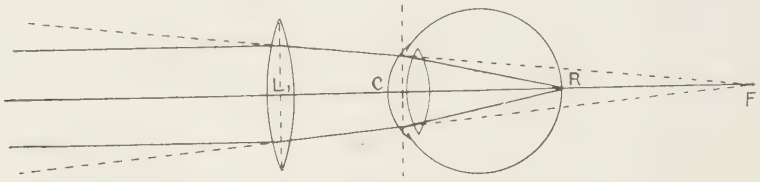


FIG. 88.

Let F represent the far-point of a hypermetropic eye. Rays converging towards this point are exactly focussed on the retina at R. In order to render this eye artificially emmetropic, a convex lens must be placed in front of it, as at L_1, whose additional refractive power will enable the eye to focus parallel rays upon the retina. It is obvious from the diagram that the focal length of this lens must be equal to the distance L_1 F, and it is also plain that other lenses at different points could produce the required effect, and that their focal lengths would be longer or shorter according as they were further away from or nearer to the eye.

The proper position for the lens is the anterior focal plane, because a + lens nearer than this minifies, and further away, magnifies.

If in this case the far-point be 236 mm. behind the eye—*i.e.*, if C F = 236 mm., then the lens required must have a focal length of 236 + 14 = 250 mm.—that is, a + 4 D. lens.

(*b*) Practice.

1. **Nearness.**—The ideal position for the spectacle-glass is the anterior focal plane (see p. 31). This cannot be attained in practice, on account of the contour of the features, eyelashes, etc. But since convex glasses increase the amount of light entering the eye, and concave glasses decrease it, and since, also, a convex lens magnifies when more remote than the anterior focal plane whilst a concave lens minifies, it is more important that concave glasses should be nearer the eye than convex. Since in many myopes the elongation of the eyeball is accompanied by impairment of the retina, it is obvious that a diminished retinal image is to be avoided as far as possible.

The magnification of the convex glasses is no inconvenience, many presbyopes preferring to wear their glasses halfway down the nose.

2. **Centres.**—Inasmuch as the optical centres of the glasses should lie on the visual lines, these points must

always correspond to the centres of the pupils. Accordingly, the optical centres must be closer together in the reading-glasses than in the distant ones, and the planes of the glasses should be at right angles to the visual lines.

3. **Bridge.**—This should be sufficiently rigid to maintain the glasses in their proper planes, as if it gets bent, the glasses may be thrown into different planes for one or both eyes, causing unequal convergence.

4. **Tilt.**—The glasses should be so adjusted that their planes are at right angles to the most frequent position of the visual lines, and in determining this the occupation for which the glasses are required should be the deciding factor. For near work, 25° with the plane of the face is a convenient angle; for distance, 10°; and for a medium for constant wear, 15.°

5. **Shape.**—The elliptical shape is sufficient for most people, since their vision is more confined to the horizontal than the vertical direction. For young, active children the circular shape is preferable, as the glasses are often prescribed with the idea of educating the eye by their means, and any tendency to peep under or over should be frustrated.

6. **Material.**—*Crown-glass* is undoubtedly the best material, as its refraction is most regular and its cost is low. The so-called *pebbles* are cut from rock-crystal, and although harder and less liable to be scratched, they must be cut with special reference to the optic axis of the crystal, and if this is not properly done the refraction is irregular. (A ray of light traversing a quartz crystal in any direction other than that of the optic axis is split up into two rays; see works on 'Polarization of Light'.)

Shot-proof spectacles are made of pebbles sufficiently thick to resist penetration by a shot. If struck, they split without shattering behind as glass does.

7. **Bifocal, or Pantoscopic Glasses.**—These consist of two lenses cemented together, or the lower part of one lens may be ground with a different curvature, the idea being *to give two pairs of lenses in one frame.* The upper is the distance-glass and the lower is for near-work. They are used in cases of presbyopes with ametropia.

8. **Stenopaic Spectacles.**—These are opaque discs, generally of vulcanite, pierced by a slit, so as to limit the vision of the patient to one direction. They are useful in certain cases of corneal opacities, conical cornea, and irregular astigmatism.

9. **Tinted Glasses.**—In cases where it is advisable to tone down the light entering the eye, tinted glasses may be given. These should be *blue* for all ordinary purposes, but the *smoked* glass should be used for such occupations as arc-lamp testing, etc.

10. **Goggles.**—Goggles are required when the eye has to be protected from dust, etc. The glass may be plane, but the sides should be framed in with fine gauze. They should be worn by tool-grinders, stone-workers, and cyclists. A more efficient protection for 'motoring' is a mask or domino to spread right across the face, with two 'windows' to look through. They should be ventilated to prevent internal condensation.

11. **Periscopic Glasses** (*peri*, around; *skopein*, to see). —So called on account of the fact that, having only slight spherical aberration, objects can be as distinctly seen when viewed through a marginal part as when looked at through the centre. (In ordinary spherical lenses the image is distorted when looked at through the marginal part.)

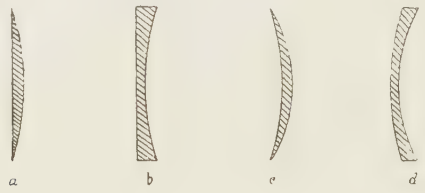


FIG. 89.

a and *b* are *plano-convex* and *plano-concave* respectively; the refracting power of these is exactly half that of ordinary spherical lenses of the same radius of curvature. *c* and *d* are *concavo-convex* and *convexo-concave* respectively. If the radius of curvature be less on the convex side (*c*), the glass behaves as a *convex* one; while if it be less on the concave side (*d*), it will behave as a *concave* one. (If the surfaces be *parallel*, as in 'protective glasses,' the glass acts as a *plane* one.)

12. **Spectacles, Folders, and Pince-nez.**—The only points to be considered in the selection of the frame in which the lenses are to be worn are the convenience and preference of the wearer, and the ability of the frame to hold the lenses before the eye so that they shall satisfy the conditions already laid down. Folders in which the lenses are drilled to receive rivets for fastening a spring are not to be recommended. Spectacles are preferable in the case of children.

CHAPTER XII

ASTHENOPIA

Asthenopia (*asthenes*, weak; *ops*, sight) literally means 'weak sight.' The term is used somewhat vaguely by medical men, but it is employed here in the definite sense of meaning that condition of eyesight in which, with no organic disease present *and any error of refraction having been corrected*, there is an incapacity for sustained visual effort, and has as its chief manifestation *eye-fatigue*, which is quite out of proportion to the ordinary work imposed upon the eyes, and is not to be confounded with the natural fatigue, the result of excessive use. Asthenopia is due either to some impairment of the *general health*, in which case the eyes share in the general weakness of the body, or it may develop in connection with some inherent *local* weakness of the muscles or nerves.

The symptoms associated with it are various, and may be briefly summarized as: An inability to read or work for any length of time without 'eye-strain,' the eyes becoming hot, uncomfortable, heavy, or beginning to ache; headache, either referred to the brows or the head generally; conjunctival irritation, photophobia, blepharitis, neuralgia, tenderness on pressing the globes, a feeling of tension or heaviness in the eyes, and occasionally diplopia, giddiness, and nausea. Sometimes a patient may complain of the eyes feeling 'like balls of fire.'

All these symptoms are liable to become specially marked towards the end of the day, and may be particularly noticeable when working in artificial light.

Principles.—When an object is looked at, the two eyes are involuntarily and simultaneously directed to it in such a way that its image falls upon each of the two yellow-spots, and the straight line extended from the centre of the object looked at to the centre of its image formed on the yellow-spot is known as the *visual axis.*

The adjustment of the eyes so as to bring the yellow-spots into alignment with the object looked at is termed *fixation.*

The *point of fixation* is the point for which the eye adjusts itself. This is, in truth, a reversal of terms, for in reality it is the object which fixes the eye. The machinery employed is the *Fixation reflex,* the centre for which lies in, or in the neighbourhood of, the *corpora quadrigemina.*

Central, Direct, or Yellow-spot Vision.—All parts of the retinal image outlined upon the *yellow-spot* are exact, sharp, and well-defined. 'The anatomical *fovea* has a breadth of from 0·2 mm. to 0·4 mm.' (Heule). By *central fixation* is implied fixation exerted so as to make the image of the object looked at fall upon the centre of the yellow-spot.

Ex-central, or Indirect, Vision.—An image outlined on the retina at a point away from the yellow-spot is less exact and sharp the farther off it lies from the yellow-spot, in accordance with the principle that the sensitiveness of the retina decreases progressively from the yellow-spot to the periphery. Immediately outside the yellow-spot the *form-sense* becomes abruptly reduced to one-tenth. *Ex-central vision* is better for the perception of *light* than *central vision,* and this explains why astronomers can see a star with greater clearness when it lies to one side of the fixation point. Ex-central vision is also highly sensitive to *moving objects.*

Identical, or Corresponding, Points.

Binocular Single Vision. — Although two retinal images of an object are formed, yet only *one* is *seen.* This is due to the fact that for each given point in one retina there is a corresponding point in the other physiologically identical with it, the two mutual points always acting together (Fig. 90). If the two eyes move in perfect unison, the two retinal images, falling upon 'identical points,' are

fused into one mental image, and so the object is seen as a single one. The psychological process herein involved constitutes *binocular single vision.*

Diplopia.—If, with one eye fixing an object, the other eye *wanders* (that is, deviates from the point of fixation), the two eyes do not move in perfect unison, the images will fall upon *non-identical* parts of the two retinæ, so that *diplopia,*

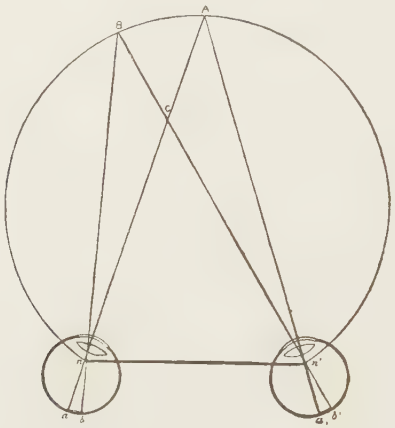


FIG. 90.—DIAGRAM TO ILLUSTRATE MÜLLER'S HOROPTER.
(*Vide* 'Euclid,' Prop. 21, Book III.)

A, point of fixation, the retinal images of which are formed at a and a^1, b and b^1 are identical points, ∴ the distance $a\ b$ = the distance $a^1\ b^1$; n, n^1 = the nodal points. The angles $a\ n\ b$, $a^1\ n^1\ b^1$ = each other, and likewise the opposite angles, A n B, A n^1 B. Also in the triangles B C n, A C n^1, the opposite angles at C are = ; ∴ in these triangles the remaining angles at A and B are = ; ∴ the point B by which the corresponding images b, b^1 are formed, must lie in the arc of a circle passing through the points B, n, and n^1. Similarly, it can be shown that any other point forming corresponding images on the two retinæ will lie in the arc n A n^1.

or double vision, results. The image seen by the fixing eye is exact and sharp, *and in its right place,* because it falls on the yellow-spot. It is termed the *true image.* On the other hand, the image seen by the deviating eye is less distinct and sharp than the other, *and is in its wrong place,* because it falls on the retina away from the yellow-spot. It is termed the *false image.*

Diplopia is known as *homonymous* (Fig. 91) when the false

image is on the same side as the deviating eye, and *heteronymous*, or *crossed*, (Fig. 92) when it is on the same side as the fixing eye, the false image formed on the *non-identical point of the retina* of the non-fixing eye *being projected into that position in space from which it has been educated to receive a stimulus*. So that the double images would be homonymous

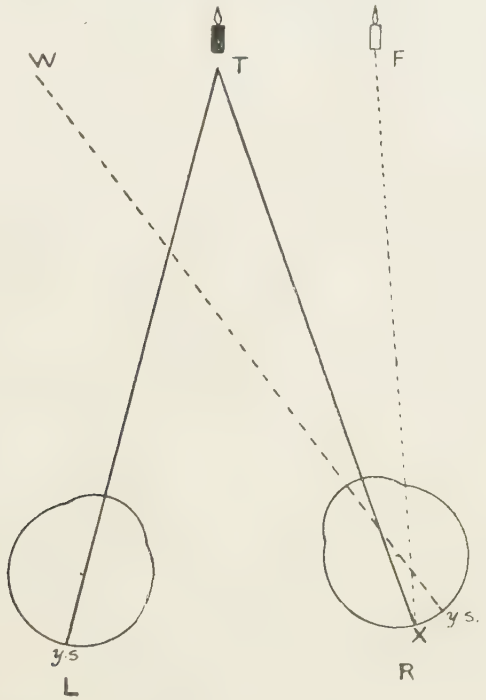


FIG. 91.—DEVIATION OF THE RIGHT EYE INWARDS (*i.e.*, towards W)= HOMONYMOUS DIPLOPIA.

ys, yellow-spot. The false image, F (represented in outline), is seen to the right of the true image, T, because the spot on the retina upon which it falls, X, has been accustomed to receive images coming the right side.

or heteronymous according as the lines of fixation intersect or not.

As Sir W. R. Gowers very well puts it, 'The student may remember the relation by the rule that when the visual lines (prolonged ocular axes) cross, the diplopia is *not* crossed.'

The Perception of Relief, or Stereoscopic Vision (Gr. *stereos*, solid; *skopeo*, I view).—A judgment of the first two dimensions of space—length and breadth—can be formed by the one eye alone. For stereoscopic vision, or the judgment of the third dimension—*i.e.*, the depth and solidity of an object (perspective)—the aid of the other eye is necessary (binocular single vision), as the two images on the

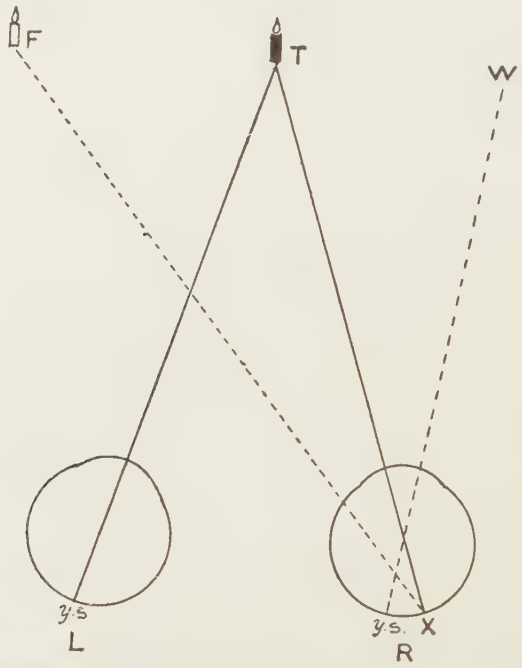


FIG. 92.—DEVIATION OF THE RIGHT EYE OUTWARDS (*i.e.*, towards W)= HETERONYMOUS OR CROSSED DIPLOPIA.

ys, yellow-spot. The false image, F (represented in outline), is seen to the left of the true image, T, because the spot on the retina upon which it falls, X, has been accustomed to receive images coming from the left side.

two retinæ form two slightly different pictures, the sum of which constitutes *stereoscopic* vision.

Monocular Vision.—In certain cases of diplopia, usually those which develop in early life, the patient can cultivate the habit of ignoring the false image. When this is so, the condition of sight is that of monocular vision, or vision with

a single eye, which implies the absence of stereoscopic vision.

Orientation is the faculty by means of which we are enabled to see objects in their right place. If the two eyes be directed forwards, an object situated to the right of the visual axis has its image to the left of the yellow-spot; an object situated to the left of the visual axis has its image to the right of the yellow-spot, and the same applies, *mutatis mutandis*, to objects situated above and below. We mentally refer objects to their proper relative positions in the external world by the psychological action of *projection*, which we learn by experience and the aid of the muscular-sense—*i.e.*, the knowledge of the exact degree of nerve-force necessary to control the normal action of individual muscles.

False Projection (or *malprojection*), *i.e.*, seeing objects in the wrong place, is the result of an erroneous idea as to the position of the eye, due to loss of the *muscular sense* in consequence of paralysis of one or more of the ocular muscles.

Tests for Binocular Single Vision.—The presence or absence of binocular single vision may be ascertained in several ways:

(*a*) Take the patient into a dark room and instruct him to fix a lighted candle placed 6 metres off in the median horizontal plane, and cover first one eye and then the other with a card. If the patient fix the object accurately, no deviation of the eye behind the cover will be noticed, nor when the cover is removed. Suppose, however, that one eye does deviate, then, on placing the cover in front of the fixing eye, *a movement of adjustment* will be observed to take place in the other eye so that it may fix the object.*

(*b*) *Prism Test.*—Place in front of one of the eyes a prism of 10°, base down, and direct the patient to look at a candle-flame situated at a distance of 6 metres, and on the same plane with the eyes. If binocular single vision exists, *vertical diplopia* will be induced—*i.e.*, two images will be seen, one standing over the other. If the prism causes no diplopia, this is evidence of the absence of binocular vision.

(*c*) *Hering's Stereoscopic or Drop Test.*—This is conducted

* *Vide* Physiological Heterophoria, p. 162.

by means of a flattened tube about 10 inches long by about 4 broad, and open at both ends. From the opposite end two wires project forwards and outwards, and attached to their extremities is a horizontal thread, at the mid-point of which is a small bead. The patient is directed to look through the tube with *both* eyes, while glass beads or marbles of different sizes are dropped from one hand into the other, sometimes *in front*, and sometimes *behind* the thread. If binocular single vision be present, no mistake will be made with regard to the true position of the beads with respect to the thread; while, on the contrary, if only monocular vision exist, frequent mistakes will be made in judging of the proper situation of the beads.

Movements of the Eyes—The Eye-muscles.

The nomenclature of astronomy has been called into requisition in speaking of the movements of the eye. Thus we talk of the *globe* moving in its *orbit* around its *axis;* we also make use of the expressions, *poles, equator,* and *meridians.*

The movements of the globe in the orbital cavity may be roughly likened to those of a ball-and-socket joint, the globe as a whole undergoing no change of position, but rotating round an immovable point, the *centre of rotation,* situated on the optic axis 11 mm. from vertex of cornea.

(N.B.—To be strictly accurate, this statement is only *approximately* true, for in the maximum excursions of the eye the globe shifts to an extent varying from 1 mm. to 2 mm., in consequence of the fact that its centre of rotation lies a little posterior to its geometrical centre.)

Field of Fixation or **Motor Field** indicates the limits of movements of the two eyes, *the head being kept still* when directing them to the four points of the compass. It is *the sum of all those points in space which the eyes can command,* and its limits represent the limits of maximum excursions of the eyes in all possible directions. It is measured by the perimeter in the following way: Fix the patient's head on the 'rest' with the eyes directed to the zero mark, and one screened. Then move the test object along the quadrant from the periphery towards the centre, and note the exact

position in which the letters can be read distinctly, recording the result on the perimetric chart. Landolt's measurements of the normal field of fixation are as follows:

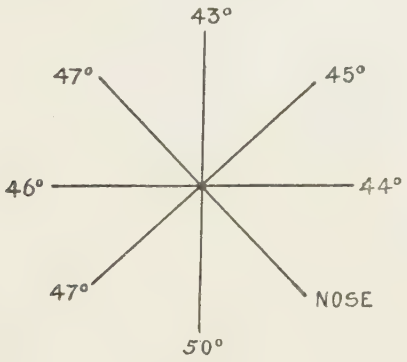


FIG. 93.

During waking-time, when there is always an unconscious active innervation of the eye-muscles, the *primary position*, or *position of rest*, of the eyes is that in which, with head erect, the visual axes are parallel, horizontal, and directed straight in front. All other positions are *secondary*.

'Tone' of the Eye Muscles.—As just stated, the normal position of the eyes during waking hours and at rest is that of *parallelism*. This is due to a slight and continuous motor discharge—the musculo-tonic action—exercised by the centres in the brain over the internal recti, and keeping these muscles in a state of *slight contraction* or *tone;* for during sleep, drunkenness, and anæsthesia, as well as in paralysis of all the ocular nerves, the position of the eyes is that of *divergence*. The term *tonic convergence* is employed by Maddox to indicate the state of parallelism of the visual axes during waking hours.

The *secondary positions* are movements of rotation round three primary axes, which together form a co-ordinate system:

(*a*) A vertical axis, about which the movements are lateral —*i.e.*, to the right and left.

(*b*) A horizontal axis, at right angles to (*a*), about which the movements are up and down.

(*c*) An antero-posterior axis, about which the movements are *wheel-like* or those of *torsion*, the upper end of the vertical meridian pointing inwards and outwards.

When the globe rotates vertically upwards and downwards,

or horizontally inwards and outwards, the movements are *cardinal* movements, and there is no torsion; but when the globe rotates diagonally, a movement of *torsion* takes place.

The visual axes are parallel when the object of fixation is distant (*i.e.*, 20 feet or more), and they converge to the same point when the object of fixation is near (*i.e.*, less than 20 feet). Any other position of the axes is abnormal.

Extra-Ocular Muscles.—The globe is rotated round its three principal axes by the individual or joint action of six muscles, all of which, with the exception of the inferior oblique, spring from the apex of the pyramidal-shaped orbit.

	Length of Tendon.	Distance of Insertion from Cornea.
Internal rectus	8·8 mm.	5·5 mm.
Inferior rectus	5·5 „	6·5 „
External rectus	3·7 „	6·9 „
Superior rectus	5·8 „	7·7 „

(Merkel and Fuchs.)

Of all these muscles, the *internal rectus is the strongest*, the respective weights being:

	Gramme.
Internal rectus	=·747
External rectus	=·715
Inferior rectus	=·671
Superior rectus	=·514

(Volkmann.)

They may be divided into three pairs, one muscle of each pair acting like a bridle on the other, being in 'co-operative antagonism' to it, viz.: (*a*) The external and internal recti rotate the eye round the vertical axis; (*b*) the superior rectus and inferior rectus rotate the eye round the horizontal axis; (*c*) the superior oblique and inferior oblique rotate the eye round the antero-posterior axis.

The external rectus rotates the eye outwards.

The internal rectus rotates the eye inwards.

The superior rectus rotates the eye upwards and inwards.

The inferior rectus rotates the eye downwards and inwards.

The superior oblique rotates the eye downwards and outwards.

The inferior oblique rotates the eye upwards and outwards.

Rotation vertically upwards is produced by the combined action of the superior rectus and the inferior oblique, and

rotation vertically downwards by the combined action of the inferior rectus and superior oblique.

To be quite accurate, it must be understood *that only the internal and external recti of the one eye are genuine antagonists*, in the sense that if one is paralyzed the result is the same as if the other had contracted. With regard to the remaining pairs of muscles, there is no such thing as perfect antagonism between them; for example, the superior oblique cannot be strictly regarded as the true antagonist of the inferior oblique, nor the superior rectus of the inferior rectus. To put the matter briefly, the antagonist of one of these muscles is not solely the other muscle which rotates the eye round the same axis in an opposite direction, but is represented by the sum of the forces exerted by several other assisting muscles which act as opponents.

Terminology.

Abduction, movement of cornea outwards (external rectus).

Adduction, movement of cornea inwards (internal rectus).

Superduction, movement of cornea upwards (superior rectus).

Subduction, movement of cornea downwards (inferior rectus).

Torsion.
- *Intorsion*, wheel-like movement, with upper end of vertical meridian inclined inwards (superior oblique).
- *Extorsion*, wheel-like movement, with upper end of vertical meridian inclined outwards (inferior oblique).

Besides these *chief* actions, each muscle has *subsidiary actions*.

The muscles receive their nerve-supply from the third, fourth, and sixth nerves, the motor neurons of which are located along the floor of the aqueduct of Sylvius and the forepart of the floor of the fourth ventricle. These motor-neurons are under the control of a higher co-ordinating centre, which in its turn is connected with a supreme voluntary motor centre in the cortex.

Orthophoria or Ocular Equilibrium.

This term has reference to that condition of sight in which the eyes work in perfect unison, whether in a state of repose, or during fixation; in plain words, when they act alike. The following experiment will illustrate the meaning of this: Let a person be required to fix an object 10 inches off, and a card be made to screen one eye; it can be seen that this covered eye, although now excluded from vision, either will still retain its position of correct fixation or may diverge up to 4°. This associated, or conjugate, action of the two eyes implies *perfect muscular balance* or *orthophoria* (Gr. *orthos*, right; *phero*, I bear), and is the outcome of the co-ordinate action of various groups of muscles, controlled by a centre in the brain. Any disturbance of the proper working of this neuro-muscular machinery causes want of balance, technically known as *insufficiency* or *heterophoria*.

Orthophoria, then, means proper or natural muscle balance, with little, or no, tendency to deviation; while *heterophoria* signifies a decided tendency to deviation, requiring a *conscious* effort of the will to control.

Physiological Heterophoria.—A divergence of 4°, while fixing an object (with one eye excluded) 10 to 6 inches off, may be taken to be the dividing limit between physiological and pathological heterophoria—that is, divergence up to 4° is to be regarded as within the normal state. 'It follows from this that in ordinary close work we habitually suppress, by our desire for single vision a deviation to this extent. Were the same deviation to exist with both eyes uncovered, we would, of course, see double; but the love of single vision will not allow it to exist under those circumstances. The unconscious effort required to suppress a deviation of normal amount in the interests of single vision is so slight that we experience no inconvenience from it. But if from any cause the deviation be a great one, the effort demanded may be sufficient to cause headache or asthenopia, and the more so if there be any debility of the system' (Maddox).

The **Causes** of asthenopia are:

(1) General; (2) Local; these often co-operate.

(1) General.—The general health exerts a profound influence on the condition of the eye and its muscles, so that any debilitated state of the system, such as influenza, recovery from an illness, childbirth, the various forms of

anæmia, may induce premature exhaustion of the neuro-muscular apparatus of the eye.

(2) LOCAL.—(i.) *Muscular*—(*a*) extra-ocular (heterophoria); (*b*) intra-ocular (or accommodative).

(ii.) *Nervous* (or neurasthenic).

(*a*) Heterophoria.

Heterophoria (*heteros*, other; *phero*, I bear) is the term now generally applied to this variety of muscular asthenopia (the 'muscular insufficiency' of V. Graefe). Here there is a weakness of the extra-ocular muscles, more especially of those concerned *in convergence, the internal recti*, and hence is most frequently found in connection with *myopia*, though it may occur in emmetropia, hypermetropia, or astigmatism. In this variety of asthenopia there is *a latent tendency on the part of one eye to deviate from its fellow and so cause diplopia*. This constant tendency to deviation can only be overcome by *a forced muscular effort*, the result of increased innervation—*i.e.*, in excess of that normally required. It is accordingly a condition not of natural, but of forced equilibrium, and so is on the borderland of squint; hence it was called *latent squint* by Von Graefe, and *suppressed squint* by Maddox. (In real squint the deviation of the axis of the eye *cannot* be overcome by a forced muscular effort.)

'A muscle of fixation may be *absolutely* or *relatively* inefficient. Absolute inefficiency may be due to some defect on the part of the muscle itself, which may be too weak, or so attached to the globe as to work at a disadvantage, or defectively innervated. Relative inefficiency, on the other hand, is due to the over-action of an opposing muscle, which may be too strong, or so attached to the globe as to work at an advantage, or excessively energized.

'It therefore follows that a muscle may have considerable power, and yet be inefficient' (Dr. Harry Campbell, 'Headache and other Cephalic Sensations').

Varieties of Heterophoria.

Taking as our standard perfect muscular balance or orthophoria, and adopting the nomenclature of Dr. Stevens, to whom we chiefly owe our present knowledge of the subject, we have:

(i.) Exophoria, a tendency to outward deviation.
(ii.) Esophoria, a tendency to inward deviation.
(iii.) Hyperphoria, a tendency to upward deviation.
(iv.) Hypophoria, a tendency to downward deviation.
(v.) Hyperexophoria, (i.) + (iii.).
(vi.) Hyperesophoria, (ii.) + (iii.).

As a very rare clinical condition, *cyclophoria* or 'rotatory' heterophoria may be found. When present, it is usually met with in astigmatism when the principal axes are oblique.

Exophoria, or latent divergence, is the commonest: the patient is unable to maintain convergence for any length of time.

Muscular asthenopia may occur with any form of ametropia, and even with emmetropia, but when of purely local origin it is generally associated with *myopia* or *hypermetropia;* for in both of these conditions there is a lack of the natural harmony between accommodation and convergence, the myope being called upon for an effort of convergence in excess of accommodation, and the hypermetrope for an effort of accommodation in excess of convergence.

Symptoms.—The eyes soon become fatigued, and ache. There are often vague sensations of discomfort referred to the eyes and head generally, and there may be indefinite feelings of languor and disinclination for prolonged visual exertion, especially writing. There may also be complaint of vertigo, and both the conjunctiva and margins of the eyelids may look reddened. Sometimes there is diplopia. If one eye be closed, the symptoms of asthenopia disappear, convergence being no longer necessary for fixation. *Heterophoria is as common a cause of headache as an uncorrected ametropia.* As the *adductors* are more used than any of the other extra-ocular muscles (being required for convergence),

it can be understood that weakness in them is likely to set up fatigue when near objects are fixed for any length of time, and this explains how the strain is chiefly felt on the inner side of the eye under these circumstances. 'Headache resulting from heterophoria has no special characters by which it may be diagnosed from headache otherwise induced. It includes every variety of pain, and may be situated in any part of the head. At one time it is a classic type of megrim, at another a supra-orbital neuralgia' (Dr. Harry Campbell). According to Culver and Dana, the headache occurring in consequence of *heterophoria* is more commonly *occipital*, while that resulting from errors of refraction is generally frontal.

Tests for Heterophoria.

(*a*) **Fixation Test.**—The normal convergence near-point is about 2 inches—approximately corresponding to the tip of the nose. Let the two eyes steadily fix an object (*e.g.*, the uplifted finger or a pencil, etc.) held in the horizontal median plane about 13 inches off. Now bring the fixation object gradually closer to the face, when it will be noticed that one eye becomes unsteady in its fixation, and after a short period of oscillation, either slowly or suddenly deviates outwards (exophoria) *before the normal convergence near-point is reached.*

(*b*) **Objective Screen Test.**—Whilst the patient is still fixing, cover one eye for at least half a minute, then suddenly withdraw the screen and notice if there be a movement of redress, which may be *inwards*, showing the presence of *exophoria; outwards*, showing the presence of *esophoria; upwards*, showing the presence of *hypophoria;* or *downwards*, showing the presence of *hyperphoria*. Or cover one eye and then the other alternately with a screen, and assume that the covered eye has wandered outwards, suddenly withdraw the screen, diplopia ensues, as the visual axis of this eye is directed outwards. To obviate the double vision, a forcible effort will be made by the deviating eye to turn inwards in order to fix the object and so effect binocular single vision.

(*c*) **Subjective Screen Test of Von Graefe.**—If the

fixing eye be suddenly screened, a candle-flame *appears to move*, because the heterophoric eye makes a movement of redress in order to fix, leading to an apparent displacement of its visual field.

(*d*) **Prism Tests of Von Graefe.**—The normal *balance, sufficiency*, or *fusion-power* of the extra-ocular muscles is regulated by the desire for binocular single vision, which is only possible when both visual axes are directed to the object fixed. This fusion-power is expressed by the strength of the prism that each muscle by *forcible effort* can overcome in order to fuse the resulting double images so that single vision shall result. (*By placing a prism before one eye, the image of the object looked at is displaced in the direction of the apex of the prism.*)

It is determined in the following way: Take the patient into the dark-room, and place in front of him a small flame 6 metres off, and on a horizontal level with the eyes.

Convergence.—Beginning with a weak one, place stronger prisms in turn before one eye, each with its base towards the temple. The strongest with which the flame remains single gives the measure of the power of the internal rectus. In a similar way test the power of the external rectus by placing the prism with its base towards the nose, and then that of the superior and inferior recti by placing the prisms with their bases respectively downwards and upwards. As there is often a difficulty in being absolutely sure that the prisms are held strictly vertical and horizontal, the inaccuracies likely to result have been obviated by the invention of Dr. Stevens' *phorometer*, an apparatus in which the prisms are geared together in a stand.

The internal recti being not only inserted into the globe further forward than the others, but being also the strongest of the extra-ocular muscles, because so much used for convergence, have a fusion-power—*i.e.*, can overcome a prism—of 30° to 50°, the external recti of 6° to 8°, the superior and inferior recti of 3°, and possibly higher.

If diplopia results from the employment of prisms of the above-indicated power, the case is to be regarded as one of heterophoria.

(*c*) **The Maddox Rod-Test.**—This is on the whole the most accurate and delicate test for heterophoria, and we owe its introduction to Dr. Ernest Maddox, formerly of Edinburgh and now of Bournemouth, to whom the profession is under such great indebtedness for advancing the science of ophthalmology. The apparatus consists of a number of cylindrical glass rods placed side by side, and mounted in a metal rim that will fit into the trial-frame. By means of this contrivance, the image of a flame as seen by one eye through the rods is *converted into a long streak of light at right angles to the axes of the rods.* 'It does not, like the prism-tests, depend on separation of the two images of an object, but on alteration of the *shape* of one of the images, so that it is no longer recognised as belonging to the same object' (Maddox's 'Tests and Studies of the Ocular Muscles,' p. 350).

Method of Application.—'Since the line of light is always of necessity at right angles to the axis, to produce a vertical streak (with which to test horizontal deviations) the axis must be held horizontally, and to produce a horizontal streak (with which to test vertical deviations) it must be held vertically. Though not essential, the test is greatly improved by using rods of red glass and holding a piece of green or blue glass before the other eye. This makes the streak and the flame differently tinted, and also makes the streak more visible by subduing the excessive brilliancy of the flame' (Maddox).

Both eyes are kept open and uncovered, and with the cylindrical bars placed in front of one eye *horizontally*, the patient is directed to look at a flame 6 metres off on the same horizontal plane with the eyes. If the muscular balance be correct (orthophoria), a red streak of light will be noticed situated vertically, and corresponding to the long axis of the flame as seen with the other eye.

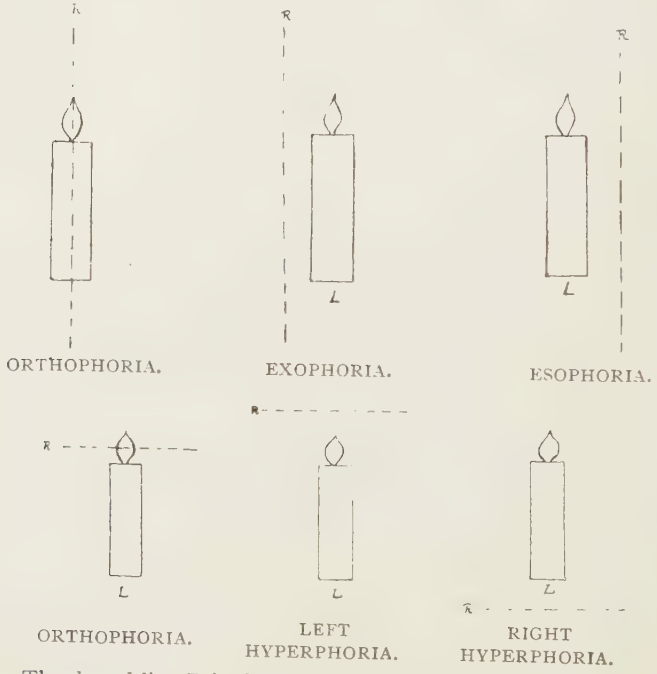
If the red streak be displaced laterally, there is heterophoria; *e.g.*, if the red streak appear to the left of the flame, there is crossed diplopia (*exophoria*); if to the right—homonymous diplopia (*esophoria*) (*vide* Fig. 94).

The amount of heterophoria is measured by the prism,

which, held in front of the Maddox rods, will cause the red streak of light to correspond exactly to the long axis of the flame.

For testing the power of the superior and inferior recti, the rods should be placed vertically, when the image of the flame will be converted into a horizontal streak of light, which should cut the flame at right angles. The amount of heterophoria is measured by prisms in the same way.

FIG. 94.—THE MADDOX ROD-TEST IN—



The dotted line R indicates the image produced by the rods.

Tangent scales for measuring the latent deviations are preferred by Maddox to any other. As Fig. 95 shows, they are made both for horizontal and vertical deviations.

'They are graduated for use at 5 metres, and are marked with large figures, representing degrees of deviation, these figures being in black to the right, and in red to the left, of the scale.

'The zero is at the centre, and there a tiny paraffin lamp

is fixed, with a small piece of black velvet behind it, to heighten its effect by contrast. The apparent brilliancy thus attained is striking. It is a good plan to have the horizontal and vertical scales, both in position, at right angles to each other, with zeros coinciding. The horizontal element of a deviation should be recorded first, and then the vertical element' (Maddox, 'Ocular Muscles,' p. 360).

TREATMENT.—The refraction of the eye is to be taken under a mydriatic, and an accurate correction of any error is to be made, and ordered to be worn constantly. *The more accurate the correction the greater the benefit.* If by these means the symptoms of asthenopia are not relieved, prisms are indicated.

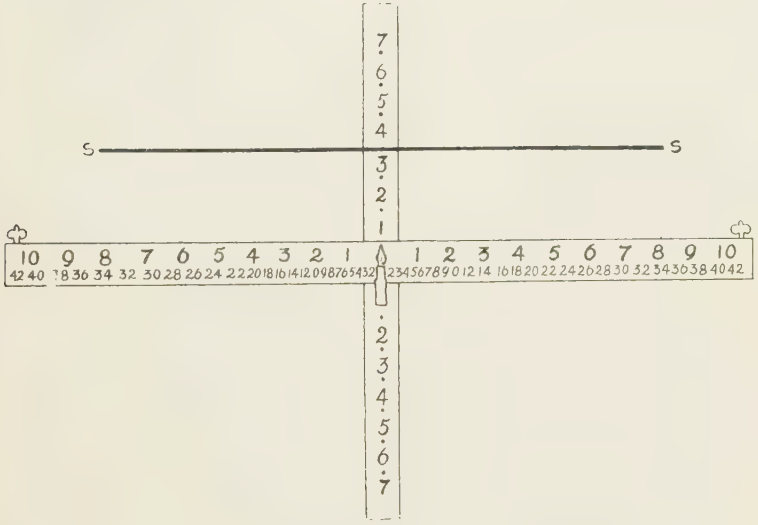


FIG. 95.

To illustrate the use of Maddox tangent scales, the streak of light being represented by S S, which (if the patient be 5 m. distant) reveals $3\frac{1}{2}^{\circ}$ of hyperphoria in the naked eye. The naked eye sees the scales only; the rod-clad eye sees the streak only (Maddox).

General Principles for correction by Prisms.

Find the sum of the correction for *both* eyes. If the insufficiency be less than 16°, take one-fourth as the maximum correction for each eye. This should rarely

exceed a prism of 4° under any circumstances, on account of the weight and chromatic dispersion a stronger prism entails. *Begin by prescribing half of this*, and increase the strength according to results.

Examples.—R.E. With Maddox rods placed horizontally, the patient sees the red streak 9° to the right, and with L.E. 7° to the left; 9°+7°=16°=total amount in the two eyes together; 16°÷4=4°. Prescribe prisms of 2° with their bases out for each eye, and change to stronger (not exceeding 4°) if found desirable.

Prisms are to be regarded as affording merely a temporary relief, and are not for permanent use. It is to be understood that they do not remove the cause of the deviation; they simply *relieve* the discomfort. It is only when other means fail that they are to be employed, and under no circumstances should they be used for too long a time, on account of the fact that their prolonged use is liable to cause an increase in the heterophoria. If spherical glasses are worn, *decentred lenses* are to be preferred.

In *exophoria*	the base of the prism must be turned			in.
In *esophoria*	,,	,,	,,	out.
In *hyperphoria*	,,	,,	,,	down.
In *hypophoria*	,,	,,	,,	up.

The general principles of treatment are so well summarized by Maddox that I transcribe his statements:

'*Simple Rules for Heterophoria.*

'1. Remember that deviations in near vision are comparatively unimportant unless in the direction of esophoria, and that in distant vision hyperphoria is at least four times more worthy of notice for each degree than horizontal deviations.

'2. If deviations cause no symptoms, leave them alone so far as special correction is concerned, yet do not ignore their evident indications, if glasses are needed otherwise, on the choice of those glasses. Thus, hypermetropes with esophoria should be fully corrected; with much exophoria under-corrected. Presbyopes with esophoria in near vision need stronger lenses than those with exophoria, and so on.

'3. Deviations which cause evident effort to overcome, with feeling of strain relieved by diplopia, and perhaps occipital headache, require treatment. It is generally best to try simple correction of refraction first, decentring the lenses a little in the direction of relief. If that fail, either orthoptic training, or stronger prisms, or operation.

'When heterophoria causes discomfort, I would suggest that—

'Three-quarters of a persistent hyperphoria should be corrected by prisms or by decentring.

'Two-thirds of a distant, or the whole of a near, *esophoria*.

'Half or a third of a distant, and a quarter of a near, exophoria.

'These rules, it need scarcely be said, are only a matter of general judgment, since each case needs its own study' (Maddox, pp. 373, 374).

Decentration of Lenses (*Vide* pages 17 and 18).

If ordinary lenses are necessary, but the action of a prism is required as well, the effect of the latter can be produced by decentring—*i.e.*, grinding the lens in such a way that the geometrical centre falls upon an excentric part.

For example, if a convex spherical glass be decentred *in*, or a concave spherical lens be decentred *out*, the effect is that of a prism with its base *in*.

So, likewise, if a convex lens be decentred *up*, or a concave lens be decentred *down*, the effect is that of a prism with its base *up*.

Rules for Correction by Decentred Lenses.

A spherical lens of 1 D., in order to produce the effect of a prism of 1°, must be decentred at 8·7 mm. Accordingly, knowing the value of the prism necessary, we multiply it by 8·7, and divide the product by the strength of the spherical lens required.

E.g., the displacement produced by a 6 D. spherical lens, combined with a prism of 2°, base $in = \frac{2 \times 8{\cdot}7}{6} = 2{\cdot}9$ mm.

Hence in this case the 6 D. lens, in order to possess the added value of a 2° prism, must be decentred 2·9 mm. inward.

If, in spite of the adoption of the above-mentioned methods of treatment, symptoms of asthenopia still persist, the eyes should be given a long rest by abandoning all forms of near work, *and protecting them from light by the use of tinted glasses*, and, in the case of young subjects, a prolonged course of atropine instillation is often necessary.

Tenotomy.—If other methods fail, tenotomy is sometimes of considerable value in well-selected cases.

(*b*) Intra-ocular or accommodative Asthenopia.

This is that variety of asthenopia due to weakness of the ciliary muscle, and is not to be confounded with the natural fatigue of the muscle, the result of excessive use of the eyes.

It may be met with in any refractive condition (after correction of the defect), but is especially apt to occur in astigmatism and anisometropia. Weakness of the ciliary muscle is principally of three kinds :

(i.) That associated with presbyopia and due to the normal decline in power of the ciliary muscle with advancing years;

(ii.) Actual paralysis, as found in diphtheria;

(iii.) *Loss of tone.*

This third variety is the most important and is the one which need alone concern us; it often coexists with heterophoria. The condition is particularly liable to develop in all debilitated states of the system, as for example, in anæmia, in the convalescence from acute diseases, in the puerperal state, in malarial cachexia, after influenza, etc.

Jessop has pointed out how common headache is among medical students, and he ascribes it in a large measure to this loss of tone consequent on the artificial and sedentary life which they lead.

It can be easily understood that a degree of ciliary weakness which in an emmetrope might cause but little evidence of its existence, would in a hypermetrope very soon induce feelings of discomfort: in fact, it not infrequently happens that hypermetropia or astigmatism may be revealed in a patient for the first time when his health is below par (much in the same manner as it may make manifest a valvular disease of the heart), the loss of tone of the muscle rendering it unable to compensate for the defect in refraction.

Symptoms.—The images of print and of all near objects become blurred, as the weakened ciliary muscle relaxes and cannot maintain a state of sustained contraction: there is often pain in the eyes and forehead: headache, megrim, and other cephalic sensations.

Sometimes the weakness of the ciliary muscle is of very brief duration, its strength being rapidly regained. 'Thus it not infrequently happens that a man jaded with a long day's work finds himself unable to read with any comfort, but after he is refreshed by dinner the strength of the ciliary muscle returns with that of the rest of the body, and reading becomes once more easy' (Dr. Harry Campbell, 'Headache,' p. 73).

Treatment.—The refraction should be taken under a mydriatic, and the glasses prescribed according to the rules laid down for the treatment of ametropia. *The more accurate*

the correction the greater the benefit; ·25 D. of astigmatism, left uncorrected, may make all the difference between success and failure. The writer never hesitates to order *presbyopic glasses* from the age of thirty years, or even earlier, for those who suffer from asthenopia and have to do much reading and writing. If by the adoption of these means the symptoms remain unrelieved, the eyes should be given a long rest by not being used for near work, and protected by *tinted glasses*. In the case of young subjects, a prolonged course of atropine instillation is often beneficial.

II. 'NERVOUS' ASTHENOPIA.

Other names for this are: *neurasthenic* and *hysterical* asthenopia. It must not be confounded with simulated blindness. In all cases of the affection it is assumed that the visual acuteness is good; and that if ametropia exist, the suitable correction has been supplied.

It is *to be regarded as a neurosis*, and most cases are found amongst hysterical young women.

The SYMPTOMS *are those arising in connection with a complicated neurosis in which the visual phenomena merely play a part.*

Alterations in the visual field, such as peripheral contraction, hemiopia, scotomata, rapid blurring, or the complete blotting out from view, of the object fixed; photophobia, pains in the eyes or head, so that the work has to be laid aside. The subjects are usually women suffering from anæmia, uterine disorder, or those convalescent from an acute disease.

TREATMENT.—The special indication in the treatment of this form of asthenopia is to attend to the constitutional state. Hypodermic injections of strychnine and the employment of the constant current will often bring about an excellent result. Fuchs recommends the application of the constant current to the cervical sympathetic. Although the symptoms may last a long time, even years, the prognosis is distinctly good.

(*Note.*—A not uncommon cause of asthenopia is the wearing of wrong glasses, more especially such as are incorrectly centred with respect to the pupils, in consequence of badly-fitting frames. A decentred lens in front of one eye, for instance, acts as a prism and means a displacement of the retinal image, necessitating an effort of squinting proportionate to the displacement in order to effect binocular single vision.)

CHAPTER XIII

STRABISMUS*

BEFORE discussing the subject of squint, it will be well to recall some of our definitions.

Field of Fixation, or **Motor Field.**—This is the area bounded by all those points in space which, *whilst the head is kept in a fixed position*, the eyes are able to command through the action of those muscles the functions of which it is to direct them in different directions. Its limits represent the limits of excursions of the eyes in all directions. Landolt's measurements of the normal field of fixation are as follows:

Outwards = 46°; inwards = 44°.
Upwards = 43°; downwards = 50° (*Vide* p. 159.

Orthophoria, or ocular equilibrium, is that condition of normal physiological equilibrium in which the eyes are able to 'fix' any object in the field of fixation *without a forced muscular effort.*

Heterophoria, or ocular non-equilibrium, is that condition in which a *forced and conscious effort* is necessary in order that the eyes may 'fix' an object without diplopia. One eye will be noticed to deviate under cover, and when this is removed there will be a movement of 'redress' in order to fix. The condition is essentially due to weakness or faulty attachment of a muscle, the one usually affected being the *internal rectus.* Being on the borderland of squint, it is sometimes termed *latent squint.*

There are transition states between heterophoria and actual squint, which may either be regarded as high degrees of heterophoria or low degrees of squint.

Fusion-power, or **Sufficiency**, of the ocular muscles is regulated by the desire for binocular single vision, which can only occur when both visual axes are directed to the object fixed; it is expressed by the strength of the prism that each muscle can, by forcible effort, overcome in order to fuse the resulting double images.

The internal rectus has a fusion-power of from 30° to 50°—*i.e.*, if a prism be held in front of the eye with its base *outwards*, the resulting diplopia can be overcome by a forced movement *inwards.* The external rectus has a fusion-power of from 6° to 8°, and the superior and inferior recti of about 3°, though it may be greater.

* Greek *strabizō*, I squint.

Strabismus, or **Squint**, is that condition in which there is a *permanent deviation* of the axis of one eye, a deviation which cannot be overcome by a forced effort of redress. In other words, in fixing an object the two visual lines do not meet at the object, but whilst the visual line of the one eye is properly directed, that of the other is *misdirected*, and the misdirection cannot be overcome by any forced effort. The misdirection of the axis of the squinting eye is called the *primary deviation*. There are two kinds of squint:

(i.) *Concomitant* or non-paralytic; and
(ii.) *Paralytic.*

In (i.) *Concomitant squint* there is no paralysis, each eye possessing its full or almost its full range of mobility, the *field of fixation* being normal, or nearly so.

In (ii.) *Paralytic squint* there is actual paralysis, the squinting eye failing to move in the direction of the action of the paralyzed muscle or muscles. The *field of fixation* is defective.

I. Concomitant Strabismus.

This is that form of squint in which there is no muscular paralysis, the squinting eye, *although its axis is misdirected*, being able to accompany the sound eye in all its movements (hence the name: *con*, with; *comes*, a companion). The misdirection of the axis of the squinting eye is the *primary deviation.*

Ordinary Test.—In order to determine which is the squinting eye the patient is directed to fix steadily an object —*e.g.*, a pencil or the uplifted finger—held about 18 inches in front of, and in the same horizontal plane with, the eyes. If a screen be then placed in front of that which appears to be the non-squinting eye, the other (squinting) eye will be seen immediately to change its position. Its previous state of misdirection will have become one of correct fixation. If the covered eye be now looked at behind the screen *it* will be noticed to have taken up a squinting position, the strabismus having shifted from one side to the other. This misdirection of the axis of the other eye whilst the squinting eye is fixing,

is known *as the secondary deviation*, and *in concomitant squint it corresponds both qualitatively and quantitatively to the primary deviation.*

If the deviation is very slight, as happens in some cases, its presence cannot be detected in this manner. Under such circumstances we must call to our aid the *diplopia test*, to be described in connection with paralytic squint.

Concomitant squint is usually either:

(*a*) *Convergent*, where the squinting eye turns inwards; or

(*b*) *Divergent*, where the squinting eye turns outwards.

Sometimes these deviations are associated with a slight upward and downward inclination.

In both cases the amount of squint is generally *a fixed quantity*, and, as a rule, habitual to the one eye; but at first it may be noticed at particular times only, when it is said to be *periodic* or *occasional*. In certain cases the squint may *alternately* affect either eye, when it is termed *alternating*.

Apparent Squint.—As before stated, it is convenient, with a view to simplicity, to assume the optic and visual axes to be the same; in reality they are not. The *optic axis* is the straight line drawn *through the centre of the cornea* to a point on the retina between the yellow-spot and the optic disc; it is the geometric axis around which the eye is symmetrical. The *visual axis* is the straight line drawn from the centre of the object looked at to the centre of the image of the object formed on the yellow-spot; *it cuts the cornea usually somewhat to the inner side of its centre.* These two straight lines—viz., the optic and visual axes—intersect one another, and the angle included at the point of intersection is *the angle alpha* (Angle Alpha, *vide* p. 36).

In emmetropia	the angle alpha	is about	5°;
In hypermetropia	„	„	more;
In myopia	„	„	less;

and in rare instances of myopia the visual axis may fall on the optic axis, or even cut the cornea outside it.

As we form our opinion of the direction of the eyes by the position of the centres of the cornea which can be seen, and not by the visual lines which cannot be seen, it will be understood how in certain cases of hypermetropia, where the angle alpha is large on account of the visual axis cutting the cornea well to the inner side of its centre, there may seem to be an apparent divergent squint; and conversely, in certain cases of myopia, for the same reason there may be an apparent convergent squint. *On applying the screen-test, however, the eye excluded by the screen will be noticed not to deviate at the instant of removing the cover.*

Diplopia. — Binocular vision is absent in the great majority of cases of concomitant squint (Von Graefe estimated in 90 per cent.), since the yellow-spots of the two eyes cannot both receive images of the object looked at (*vide* Fig. 96, and also chapter on Identical Points). In a small number of cases, however, it is perhaps possible that a region in the retina eccentric to the yellow-spot of the squinting eye can be educated to become *functionally identical* with the yellow-

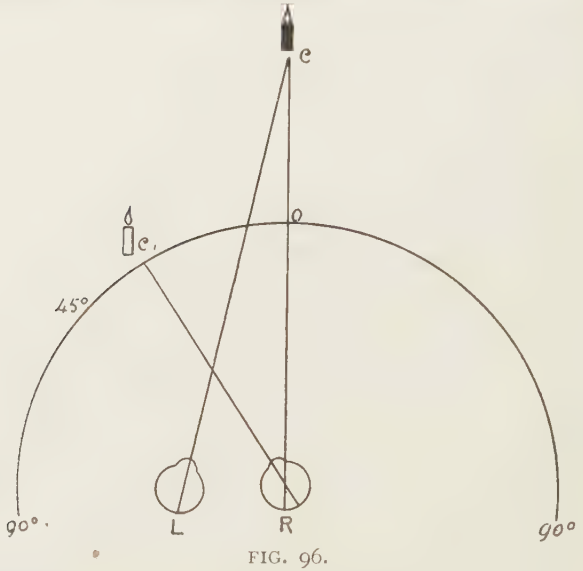


FIG. 96.

The squinting eye, R, occupies the centre of the perimeter. The non-squinting eye, L, fixes the candle-flame, C, 5 metres off. The image of the candle-flame, C_1, occupies the centre of cornea of R. The angle of strabismus is at the point of intersection of the straight line drawn from C_1 with C O R, and is measured by that number of degrees on the perimetric arc which corresponds to the position of the flame—*e.g.*, in this diagram about 30°.

spot of the fixing eye, and so allow of binocular vision. Inasmuch, then, as binocular vision is absent in an ordinary case of concomitant strabismus, diplopia should be present, but, as a matter of fact, it is but very rarely found. The explanation usually given of this is that, although diplopia may have existed at the very commencement of the squint, in course of time the patient acquires the habit of excluding or

suppressing the image formed on the retina of the squinting eye, just as in the same way one may learn, in the case of the ears, to exclude the annoyance of a troublesome sound.

Measurement of Concomitant Squint.—There are several methods of estimating the degree of squint; the one in common use is that of finding *the angle of strabismus* by means of the perimeter.

Definition.—The angle of strabismus is the angle which the visual axis of the squinting eye makes with the direction it should have if normally directed—*i.e.*, if it were fixing correctly.

Assume the case to be one of ordinary convergent strabismus (Fig. 96). Let the patient be seated behind the perimeter with the quadrant horizontal, his chin resting on the support, and the squinting eye on the same median and horizontal plane as the zero mark *o*. Let a distant object (such as a lighted candle 5 metres off) lying in the median plane be fixed by the patient, whilst the observer moves along the arc of the quadrant a lighted candle, keeping his eye all the time behind it, *and notes the reflection of its flame falling on the front of the cornea of the squinting eye.* The movement of the candle should be continued until the corneal image *exactly corresponds to the centre of the pupil*, and the degree on the quadrant at which this occurs will express the size of the angle of strabismus.

The centre of the cornea indicates the position of the optic axis, and not that of the visual axis; but, as before explained, the two for all practical purposes may be regarded as identical.

The Strabismometer.—This is nothing more than an ivory plate, so shaped as to adjust itself readily to the lower eyelid, the free border corresponding to that of the lid. This border is graduated in such a way that, while its mid-point is indicated by O, millimetres are marked off to right and left of the centre. It is practically obsolete.

The Tangent Strabismometer.—The following very admirable method was devised by Dr. Ernest Maddox, of Bournemouth. I subjoin his own description:

'The tangent scale (obtainable from Messrs. Curry and Paxton), constructed for use with the rod-test, is the only apparatus needed, and since it hangs on the wall, it occupies no space in the room, and is ever ready. It is in principle a flattened-out perimeter. It serves for both the objective and the subjective measurement of squint, and whenever diplopia can be

elicited, both should be made ; for while, on the one hand, subjective measurement is far more delicate than any objective measurement could possibly be, on the other hand there is the chance of meeting with one of those occasional fallacies in the projection of the false image which need checking by rougher though more dependable objective observations.

'The *large* figures on the tangent scale are not intended for ordinary strabismometry, but rather for latent deviations or slight squints (under 10°), since they represent degrees for a distance of 5 metres.

'The row of *smaller* figures is added for strabismometry, and being intended for use at 1 metre, since they stand for degrees at that distance, a piece of string 1 metre long hangs from the candle ready to adjust the distance of the patient.

'*Mode of Use.*—Placing the patient facing the candle at the metre distance, the surgeon introduces his own head between the two, but a little lower down, about a foot away from the patient, and so that the root of his own nose is vertically under the rays of light which proceed to the patient's eyes. At once the tell-tale corneal reflections reveal which eye is the squinting one, and the amount of squint being guessed at by the degree of eccentricity of the reflection, the patient is told to look at the figure which numerates the guess.*

'If the guess be true, the squinting eye has been brought straight for the candle, and the reflection upon it occupies its proper position.

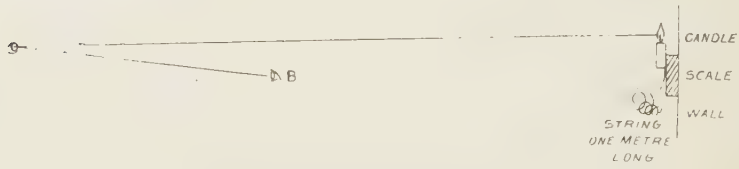


FIG. 97.—TANGENT STRABISMOMETRY. TO SHOW THE PATH OF THE LIGHT FROM THE CANDLE. (Maddox.)

'If the guess be only partially correct, successive figures are mentioned, one by one, for the patient to look at, till the surgeon is satisfied as to the right one. For rapid work this suffices, and takes scarcely more than half a minute. Since the height of the patient is immaterial, no time is lost in adjusting it, as in the use of the perimeter.

'Greater accuracy still may be secured by screening the working eye, and making the squinting one fix the flame for a moment to see what the *fixation position* of the corneal reflection is, and whether it is similar to that of the working eye.

'1. *Concomitancy* can be measured by repeating the observation with the patient's face turned to one side and the other (Berry).

'2. The *secondary deviation* can be measured by screening the working eye, and making the squinting eye (and the face) look at a figure which

* 'According to Hirschberg, when the reflection occupies the margin of a moderate-sized pupil, there is about 15° or 20° of squint ; when the margin of the cornea, about 45°. For divergent strabismus the figures are less. The angle gamma has to be considered always.'

brings the working eye straight for the candle, as proved by momentary unscreening to look at the corneal reflection ; or by a little adeptness the working eye can be screened from the figure looked at by the other eye, yet not from the flame.

'3. The *angle gamma* can be measured by making the eye look at the figure which brings the reflection precisely into the centre of the cornea.

'4. The degree of *eccentric fixation* (or the position of the "false macula" of some authors) is measured by subtracting the angle gamma of the sound eye from the apparent angle gamma of the squinting one.

'5. *Imperfect abduction* of the squinting eye can also be measured by rotating the head.

'6. The *accommodative element* can be eliminated by holding the correcting lenses before the fixing eye ; or its increase can be tested by holding a minus lens similarly.

'7. Any *vertical elements* in the squint can be measured by temporary adjustment of a vertical scale, as in Fig. 97, after measuring the horizontal element ; the vertical scale being placed under the figure on the horizontal scale which has been previously settled on, the patient being made now to look at that figure on the vertical scale which brings the reflection to the "fixation position."*

'The rapidity of measurement by this method favours the good practice of measuring squints before and after operation, which is generally at present dispensed with to save time. Another advantage is that it leaves both hands free to analyze the squint.

'*Effect of Tenotomy.*—The average effect produced by a tenotomy differs, of course, with different operators and in different cases, but about 16° may be reckoned a good effect (Berry).

'*Subjective Strabismometry.*—The subjective test is made by holding a disc of red glass rods before the squinting eye and reading off that figure on the same scale which appears crossed by the streak of light. A piece of blue or green glass before the working eye improves the effect by making the images more dissimilar in colour and more equal in intensity.

'*Concomitancy* can be measured by turning the face to one or other side, as before, and comparing the readings.

'*Direction of Fixation.*—In both the above tests the patient's face can, if desired, be turned towards the figure he is fixing, so as to gain the advantage of measurement under the usual conditions of vision with the fixing eye looking straight forwards.'

Diagnosis.—In the large majority of the instances there is marked deviation of one eye. Except when the squint is first developed, diplopia, as a rule, is not present, because the patient soon acquires the habit of *suppressing* the 'false' image. Binocular vision being absent in these cases, there is a loss of stereoscopic vision (*i.e.*, an incapacity to appreciate

* 'Though not necessary in practice, a little calculation would have to be made in scientific inquiries to correct the variable angles subtended by the figures in the vertical scale in different situations.'

the third dimension). *There is almost always anisometropia*, the error of refraction being greater in the deviating eye, the visual acuteness of which is generally much reduced. The mobility of the *two* eyes is usually slightly defective, outwards in convergent, and inwards in divergent squint, and more so in the squinting than in the fixing eye.

Images formed in the Deviating Eye.—1. There is the image of the object seen by the fixing eye. This in the deviating eye falls elsewhere than on the yellow-spot, and it is this which, *if perceived*, would cause diplopia. But from congenital amblyopia, ametropia, and 'suppression,' perception thereof is lost.

2. The yellow-spot in its abnormal situation receives an image of some object other than that fixed by the eye in use. But amblyopia, ametropia, and 'suppression' also play their parts in this case. 'Suppression' in this instance is perhaps analogous to that habitually practised by eyes normally placed; that is, in distant vision there is always diplopia of near objects, this diplopia being ignored by the brain; and, *vice versâ*, in near vision there is diplopia of distant objects.

(*a*) Convergent Concomitant Strabismus.

Convergence.—Under ordinary conditions the normal position of the eyes at rest is that of *parallelism*. This is due to a slight and continuous motor discharge—the musculo-tonic action—exercised by the centres, and keeping the muscles of convergence in a state of slight contraction or *tone*. During sleep, drunkenness, and anæsthesia, as well as in paralysis of all the ocular nerves, the position of the eyes is that of divergence.

The term *tonic convergence* is employed by Maddox to indicate the state of parallelism of the visual axes during the waking hours. As an *abnormality* it may manifest itself either as *an excess* or *deficiency of tonic convergence*. *Excess of tonic convergence* in *distant* vision may occur *temporarily* after excessive convergence for near work, and sometimes permanently in certain myopes who hold their work close to the eyes. It is also frequently found in uncorrected hypermetropes.

Deficiency of tonic convergence, or latent *divergence* in *distant* vision, may occur in any condition of refraction, but is most commonly associated with myopia, especially if one eye be amblyopic.

In convergent concomitant squint, when one eye fixes an object the other eye deviates inwards. On its first appearance the squint is usually noticed only at uncertain *intervals*, when it is said to be *periodic or occasional*, and it may shift from one eye to the other, when it is said to be *alternating*. Ultimately, however, it tends to become localized in and habitual to one eye, when it is said to be *unilateral* and *constant*. It may, however, *remain always alternating*.

Mr. Edwin Holthouse, who has investigated the subject very thoroughly, believes that *alternating* cases constitute about 10 per cent. of the whole number of non-periodic convergent squints.

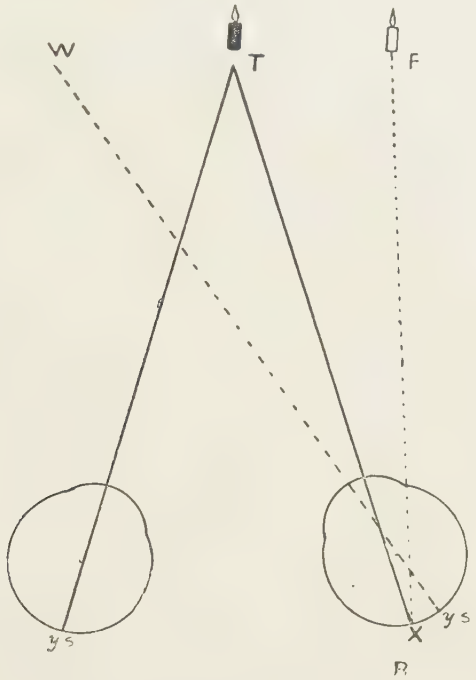


FIG. 98.—DEVIATION OF THE RIGHT EYE INWARDS (*i.e.*, TOWARDS W). HOMONYMOUS DIPLOPIA.

The visual axis of the left eye, L, is directed towards the object T, and the visual axis of the right eye is directed towards W. Since the object T has its image on the *ys* of the left eye, this image is the *true* image. The right eye, however, has the image of the object T falling upon X—*i.e.*, upon a point internal to the *ys*—and since this particular part of the retina has been accustomed to seeing objects as coming from the left at F, the false image will be referred to F. So the false image will occupy a position *on the side corresponding to the squinting eye*, and the diplopia is homonymous.

In the large majority of instances *convergent* squint is found to be associated with *hypermetropia*. It is also occasionally found in connection with *emmetropia*, and even in *myopia*.

(*Note*.—In concomitant squint the two eyes can never squint simultaneously.)

There is *anisometropia* as a rule, the squinting eye exhibiting the greater amount of refractive error. The *fixing* eye is usually hypermetropic, but the squinting eye is generally found to be astigmatic as well as *hypermetropic*, with its visual acuteness below the normal standard—*i.e.*, after full correction, $V = \frac{6}{12}, \frac{6}{18}, \frac{6}{24}, \frac{6}{36}, \frac{6}{60}$, and in extreme cases $\frac{1}{60}$—or even complete amblyopia.

The deviation almost always begins to appear in early life (nearly always at about two or three years of age), at the time when accommodation and convergence are first brought into use in order to fix near objects continuously.

Etiology.—Donders found hypermetropia in 77 per cent. of cases of concomitant convergent strabismus, and he sought to explain the phenomenon on the hypothesis that in hypermetropes there is a disturbance of the normal balance between accommodation and convergence. A young hypermetrope of 3 D. would require 3 D. of accommodation to enable him to see distant objects clearly. In order to see at the distance of $\frac{1}{2}$ metre, it would be necessary for him to accommodate to the extent of 5 D. With 5 D. of accommodation, however, there should conjointly be used 5 metre-angles of convergence (*vide* chapter on Convergence); but in this case only 2 metre-angles of convergence are required for the distance of $\frac{1}{2}$ metre.

One or two things must then follow: (*a*) Either he elects (unconsciously, of course) to sacrifice some of his accommodation and to use a reduced amount—*i.e.*, that amount which normally goes with the amount of convergence actually required—*and so to retain binocular vision*, but at the expense of seeing near things indistinctly; or (*b*) to use the full amount of the accommodation required to see near objects clearly, sacrificing binocular vision for that purpose. In this latter case convergent strabismus is the result.

Concomitant convergent squint is said to be generally found associated with the more moderate degrees of hypermetropia, *being less frequent in the higher degrees of that defect*. Donders explains this fact in the following way: In high degrees of hypermetropia the accommodation is inadequate to furnish a perfect retinal image (for a sustained effort only about two-thirds of the accommodation can be kept up). Hence the child accustoms himself to an imperfect image by sparing his accommodation rather than to improving the retinal image by straining his ciliary muscle. An effort of convergence under these circumstances would bring no advantage with it.

The writer agrees with Mr. Edwin Holthouse, that *high* degrees of hypermetropia are rare, and in thinking that *in proportion* convergent strabismus is just as common as in the lower degrees.

Another objection to Donder's theory is the fact that convergent squint may occur *in emmetropia* and *also in myopia*, but against this is the fact that the eye may have been hypermetropic when the squint began.

Although the question is still *sub judice*, the general consensus of opinion is that it is the outcome of two separate factors acting in conjunction:

(*a*) *A lessened visual acuteness in one eye, co-operating with*
(*b*) *Esophoria* (latent squint, *vide* p. 164).

(*a*) In nearly every case there is a decided lessening of visual acuteness in the squinting eye, which is *usually congenital*.

But this reduction of visual acuteness *may also be acquired* as the result of opacities in the media or from disease of the fundus. Occasionally the congenital amblyopia is not merely partial, but complete.

(*b*) If *esophoria* be regarded as latent squint, *then convergent strabismus may be considered as an esophoria which has become a manifest and immutable squint*.

It has been explained in the chapter on *Heterophoria* that the annoyance that would result from diplopia is overcome by the forced effort of a weakened muscle.

If, in a given case of *esophoria* there be diminution in the visual acuteness of the deviating eye, the false image formed in this eye will be less troublesome and annoying than if perceived by an eye of which the visual acuteness is good, because it will be less exact and sharp. A concomitant convergent squint usually develops in early life, and the child, in order to relieve himself of the strain of a forced muscular effort (*movement of redress*), begins by tolerating this false image and ultimately acquires the power of mentally suppressing it.

Reduction of Acuteness of Vision in the Squinting Eye. — Considerable discussion has arisen as to whether the reduction in the visual acuteness of the squinting eye is congenital or acquired. The balance of evidence seems to be in favour of the view that a certain degree of defect in visual acuteness exists before the development of the squint, but that from disuse of the deviating eye it becomes more and more marked. Certainly, the older the patient the worse the sight in the squinting eye is found to be, as a rule; in some cases being even lower than $\frac{1}{60}$.

PROGRESS.—Most convergent squints tend gradually to lessen as the patients become older, a fact to be ascribed to the growth of the eye.

TREATMENT.—Atropine is to be used for at least a clear week, and the error of refraction estimated whilst the eyes are

fully under its influence. *The full correction is to be given by glasses for constant wear*, and it is advisable that the eyes be kept under the influence of atropine for some weeks, or even months, after the adoption of spectacles. Should the continued use of the atropine cause photophobia, the correction should be made by means of blue or tinted spectacles during this time. The use of glasses may be commenced as early as three years of age. The employment of the eyes for near work is to be forbidden.

Orthoptic Exercises.—This treatment is based on the following principles:

(*a*) In convergent strabismus there is reduced visual acuteness in the deviating eye, leading to the suppression of binocular vision; and also—

(*b*) A want of proper co-ordination between convergence and accommodation.

The method of treatment, then, is:

(i.) To correct the ametropia by glasses, and to educate the weaker eye by training applied to it only, thereby improving its visual acuteness and working powers.

(ii.) To make the squinting eye conscious of its misdirection by causing diplopia, and to induce it to correct this by re-establishing binocular vision.

The special aim, then, of orthoptic training is to *re-educate the eye for the functions of binocular vision and of convergence.*

Javal Orthoptic Exercises (*Tscherning's résumé as given by Maddox*).

'(*a*) *Re-establishment of the Diplopia and, if possible, of the Vision of the Squinting Eye.*—The good eye is kept covered by means of an intransparent shell. If the vision of the other eye is too poor, to persecute the patient less we let him wear the shell over the defective eye for some hours of the day; but we must not during this period of the treatment ever permit both eyes to be uncovered at the same time, under penalty of never seeing the habit of suppressing the false image disappear or of seeing the squint increase, for diplopia gives less trouble in proportion as the images are removed from each other, so that the patient sets himself squinting more strongly to separate the images.

'(*b*) *Re-establishment of the approximately correct Position of the Eyes by Operation.*

'(*c*) *Stereoscopic Exercises.*—We commence by placing in each field and in each visual line a round spot. If the patient fuses these, we make them approach or recede to develop his power of seeing single. Javal's stereoscope, an imitation of Wheatstone's, but with a variable angle

between the mirrors, lends itself very well to this exercise. As soon as the patient sees double we begin again. When the patient has succeeded, we make him fuse letters by giving them to him in smaller and smaller types. In all these tests each figure must have a number of small marks added to it, different for each eye, in order to assure ourselves that the patient really fuses. The figure must be seen with both series of marks, otherwise there is suppression of one of the figures instead of fusion of the two. In beginning these exercises, we often meet with the phenomenon which V. Graefe designated by the name of antipathy against single vision. When we place the circles in situations which correspond to the visual lines, the patient converges or diverges in order not to fuse them; if we try again in this new position of the eyes, he alters his convergence again, and so on. Javal has invented a very ingenious card to get over this difficulty, which is often a very great one.

'(*d*) *Exercises without Stereoscopes.*—There is often one part of the field in which the patient sees single. We then put him through exercises to extend this part—for example, by placing a candle in the part of a field where the patient fuses, and in bringing it towards the other part. As soon as the patient sees double we begin again.

'(*e*) If the patient succeeds with these different tests, we begin to make him try *controlled reading*. A pencil is interposed between the eyes and a book; reading cannot then take place without interruptions, except by using both eyes. This exercise must be continued for months. It is not until a long time after the re-establishment of binocular vision that the patient can perceive "relief."'

The prices of the ordinary stereoscopes (Wheatstone's, etc.) are, unfortunately, quite prohibitive for hospital patients. A small and inexpensive one has lately been introduced by Mr. Brooksbank James, which can be strongly recommended (*Lancet*, September 2, 1902).

OPERATIVE TREATMENT.—Upon a patient under the age of eight, it is a general rule that no operation should be done unless the squint be of very high degree. Up to this time we should always persevere with glasses, and hope for a successful result. After this age, however, if no improvement have resulted from the use of glasses, an operation is indicated, viz: a tenotomy of the internal rectus of the squinting eye, either with or without an advancement of the external rectus of the same eye. Some surgeons prefer tenotomy of the healthy eye. The author considers it a matter of very great importance to keep both eyes, after a tenotomy, under the influence of atropine for at least two to three months, the fully-correcting glasses being worn all the time. The success or failure of a tenotomy, in the writer's opinion, largely

depends upon carrying this out. In doing the operation, it is important to bear in mind *that absolute parallelism of the eyes is not required at once*, for the effect of the operation tends to go on increasing during the first year after its performance, and from being convergent it sometimes happens that a squint becomes divergent as the result of the tenotomy.

If the squint be of *very high degree*, and no improvement results from the use of glasses after *a six months' trial*, tenotomy should be performed without further delay, because by so doing we stand a better chance of restoring binocular vision.

(*b*) Divergent Concomitant Strabismus.

In this variety of squint, when one eye fixes an object the other eye deviates outwards. It is much rarer than convergent squint. It is usually associated *with myopia* (about 65 per cent.), and *the greater the degree thereof the greater the tendency to the development of a divergent squint.* As myopia usually makes its first appearance after the age of eight, this form of strabismus is but rarely found in young children, but it develops during the period of youth—when the myopia becomes pronounced. Though rare, it may occur in connection with either emmetropia or hypermetropia. Independently of myopia, it is very likely to develop when the sight of one eye is much impaired or lost, as from marked opacities of the media, disease of the fundus or optic nerve, or other conditions causing partial or complete blindness—since under these circumstances binocular vision being impossible, there is no need for convergence, tonic or otherwise. Divergent squint may also be brought about by an unscientifically performed tenotomy of the internal rectus.

Etiology.—It is with an *uncorrected* myopia that this form of squint is liable to develop. As before explained, accommodation and convergence are linked functions, the employment of a certain amount of accommodation necessitating under ordinary conditions the employment of a corresponding amount of convergence. In uncorrected myopia but little accommodation is required, in the higher degrees hardly any, and in extreme degrees none at all. It would appear that *when the stimulus of accommodation is withdrawn, convergence becomes weakened*, and in divergent squint this weakening has proceeded to actual relaxation of the internal recti; in other words, latent divergence (*exophoria*) has passed into divergent strabismus.

In a case of, say, 10 D. of myopia, the far-point is 4 inches from the eye. To see objects at this distance excessive convergence is necessary; accordingly, the internal recti are liable to become fatigued, to relieve which one internal rectus relaxes and the eye deviates outwards, an event more particularly liable to happen if its visual acuteness is defective. Since the squinting eye turns outwards, there is no need for the fixing eye to converge at all.

At first the divergence is *periodic* and only to be noticed when near objects are looked at, but in course of time it becomes *constant*.

When there is myopia, the diverging eye is usually the more myopic, and frequently amblyopic as well.

If *exophoria* be regarded as *latent squint*, then divergent strabismus may be considered as an exophoria which has become a manifest and immutable squint.

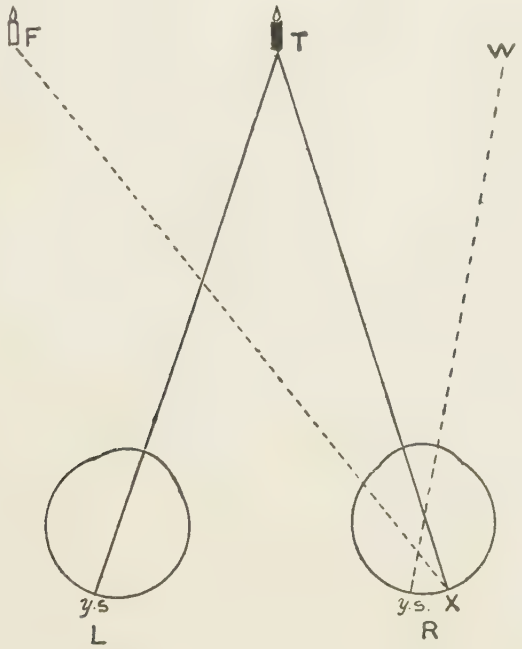


FIG. 99.—DEVIATION OF THE RIGHT EYE OUTWARDS (*i.e.*, TOWARDS W). HETERONYMOUS OR CROSSED DIPLOPIA.

The visual axis of the left eye is directed towards the object T, and the visual axis of the right eye is directed towards W. The false image, F, is seen to the left of the true, because the spot of the retina X upon which this falls has been accustomed to seeing objects as coming from the left side; accordingly the diplopia is *crossed*.

TREATMENT.—The error of refraction is to be estimated under atropine, and the fully-correcting glasses ordered for

constant use. This alone, however, does not, as a rule, remove the squint. To effect a cure, it is generally necessary to do tenotomy of one or both of the external recti, and in marked cases this must be supplemented by an *advancement* of the internal rectus of the squinting eye, and sometimes of the other eye as well. To restore binocular single vision, the operation must be followed by stereoscopic exercises practised several hours a day for months (Javal).

II. Paralytic Strabismus.

Paralytic strabismus is that form of strabismus due to defective action of an ocular muscle or muscles, the deviation of the eye being caused by the unopposed action of the antagonistic (healthy) muscles.

Anatomical.

Action of the Eye Muscles.

If each muscle could contract alone, the actions would be as follows:

The *external rectus* rotates the eye directly outwards.

The *internal rectus* rotates the eye directly inwards. *It is the strongest of all the ocular muscles.*

The *superior rectus* rotates the eye upwards and slightly inwards, inclining the upper end of the vertical meridian inwards.

The *inferior rectus* rotates the eye downwards and somewhat inwards, inclining the upper end of the vertical meridian outwards.

The *superior oblique* rotates the eye downwards and outwards, and inclines the upper end of the vertical meridian inwards.

The *inferior oblique* rotates the eye upwards and outwards, and inclines the upper end of the vertical meridian outwards.

Inasmuch as when the eye is moved in a certain direction the eyeball does not change its position to any significant extent (less than 2 mm.), but rotates round an almost stationary centre (the 'centre of rotation'), it is probable that when a particular muscle contracts there is a

simultaneous, though less forcible, contraction of the antagonistic muscle or muscles, the purpose of which is the *steadying of the eye* and the prevention of oculation ('the co-operative antagonism' of the physiologists).

The *third nerve nucleus* is situated beneath the floor of the aqueduct of Sylvius. It supplies:

Anterior part { *Ciliary muscle* / *Sphincter iridis* } Unstriped muscle.

Posterior part { *Levator palpebræ superioris* / *Superior rectus* / *Internal rectus* / *Inferior rectus* } Striped muscle.

The *fourth nerve nucleus* is also situated beneath the floor of the aqueduct of Sylvius. It supplies the *superior oblique*.

The *sixth nerve nucleus* is situated beneath the floor of the fourth ventricle. It supplies the *external rectus*.

All these three nuclei are connected by commissural fibres.

When the paralysis is incomplete or partial, the term *paresis* (Gr. *pariemi*, to relax) is generally applied to the condition.

There are many possible degrees, ranging from very slight paresis—when there is no visible squint—to absolute immobility.

SYMPTOMS.—The symptoms may be briefly summarized under seven headings:

1. Restriction of movement (primary deviation).
2. Strabismus.
3. Secondary deviation of the sound eye.
4. False projection of the visual field of the paralyzed eye.
5. Ocular vertigo.
6. Altered position of the head.
7. Diplopia.

1. *Restriction of Movement (the Primary Deviation).*—The patient can no longer simultaneously direct *both* visual axes towards an object placed in that part of the motor field dominated by the affected muscle, the paralyzed eye failing to move in the required direction, and this to an extent proportionate to the degree of the paralysis (*the primary deviation*). It is commonly tested by making the patient

follow the tip of the finger with both eyes, as it is passed in different directions. As the limit of movement is reached, there may be nystagmus, or the movements may become jerky. (Alfred Graefe laid it down as a rule that the inner side of a moderately dilated pupil should be made to coincide with a vertical line drawn from the lower punctum—if the internal recti are acting with their normal vigour.)

2. *Strabismus.*—The paralysis may be always apparent, or in the lesser degrees may be manifest only when the eye is turned in the direction controlled by the affected muscle.

As a paralyzed muscle does not lose its elasticity *at once*, the effect of the loss of power may be very slight at first, so long as the unaffected eye is in the *position of rest;* but *in course of time the eye deviates more and more*, owing to what physicists term *loss of elasticity*, and, aided perhaps by what the neurologists call *contracture of the antagonist.* The *amount of deviation* of the squinting eye is determined chiefly by (*a*) *the degree* of paralysis, and (*b*) *the duration* of the paralysis.

In the slightest forms of paresis the impaired mobility may not be detected—*i.e.*, no actual squint may be objectively noticeable, in which case the diagnosis must be based upon the characters of the double images, and the special diplopia test called into requisition to reveal its existence. The strabismus only occurs in the positions requiring the action of the affected muscle, in which respect it differs from concomitant squint.

Differential Diagnosis between Concomitant and Paralytic Squints.—In *concomitant* squint the amount of primary deviation remains *the same* in whatever direction the eye be moved; in *paralytic* squint the amount of primary deviation *increases* while the eye is moved in the direction of the action of the affected muscle. In the one case the conjugate movements of the two eyes are equal in all directions; in the other case the conjugate movements are equal in certain directions only, but unequal in other directions.

3. *The Secondary Deviation.*—If the eyes be moved in the direction of the action of the paralyzed muscle, the healthy eye will move to the full extent, but the affected one will squint, and the deviation will be the more marked the greater the effort made. This misdirection of the axis of the squinting-eye is termed the *primary deviation.*

If the squinting eye be made to fix an object by placing a

screen in front of the healthy eye, the latter will now be found to squint, its misdirection being termed the 'secondary deviation.' *The secondary deviation in paralytic squint is always greater than the primary deviation.* (In concomitant squint the secondary and primary deviations are equal.)

In *paresis* of a muscle, the secondary deviation is often more easily observed than the primary. The reason that the secondary deviation is greater than the primary is because a stronger impulse than usual is necessary to induce the faulty eye to *fix*, and the extra effort to do this as well as it can be done causes excessive action of the muscle of the healthy eye with which its action is normally associated. The result, therefore, is that a greater movement of the latter takes place than would be the case if it received only its ordinary stimulus.

Yoke-fellow.—In the normal movements of the eyes—for example, to the right or left—the external rectus of one eye contracts simultaneously with the internal rectus of the other, the one muscle being 'yoke-fellow' to the other.

Assume, for the sake of illustration, that the right external rectus is paralyzed; the right eye then would deviate inwards, and could not be turned outwards. If an attempt is made to look to the right, a stronger impulse than usual is sent down to the paralyzed muscle; but this excessive impulse is equally transmitted to the internal rectus of the left eye, for these two muscles being 'yoke-fellows,' are used together in looking towards the right, and are innervated from the same 'association centre.' Hence the sound muscle contracts more vigorously than it would in normal circumstances.

The *secondary deviation* has been likened to the conditions that would obtain in driving a pair of horses with unequally sensitive mouths, when an attempt to turn the couple would cause a greater effect on the horse with the normal mouth than on the one with the hard mouth. The *secondary deviation* may be discovered when the *primary deviation* is too slight to be noticed; it is therefore a very delicate and reliable test of paresis of a muscle.

4. *False Projection of the Visual Field.*—A judgment of the position of objects in the visual field is based on the amount of nerve-force sent to a muscle—the *out-going current,* as it is termed. The squinting eye does not see objects in their right places, but forms an erroneous estimate of their positions in space. For example, if the healthy eye be covered, and the patient be told to touch *quickly* (not

slowly, for he would then have time to correct the mistake) with his right index-finger an object in front of him, he will fail to do so, his finger moving to a phantom image that occupies the position of that side of the object which corresponds to the side of the paralyzed muscle. The explanation of this *false projection* is that the position of an object is (unconsciously) estimated by means of *the 'out-going' current*, the increased innervation necessary to force the paralyzed muscle into action suggesting a greater movement than has actually taken place. In this way the erroneous judgment is formed that the object looked at is more to one side than it really is, and the patient unaware that he has over-estimated the amount of movement, refers the object to a position it does not really occupy.

5. *Ocular Vertigo.*—As a consequence of the *false projection* of the visual field there results, when the patient moves his eyes or walks about, a distorted impression of external objects, the chief effect of which is *giddiness*. The explanation of this symptom is that one of the chief guides to the centres which control the equilibrium of the body is the degree of nerve stimulus of the eye muscles during fixation. For example, if in a case of paralysis of the superior oblique, the healthy eye be covered and the patient is directed to walk across the room, he will experience *giddiness*, which may be so marked as to make him stagger in his gait like a drunken man. This giddiness, resulting from paralysis of any of the extra-ocular muscles, is termed *ocular vertigo*. It can only occur when an attempt is made to put the paralyzed muscle into action.

Many patients, however, learn to escape the annoyance caused by the false projection and the associated vertigo, either by shutting the *affected eye*, or else by inclining the head in such a way as not to call into action the paralyzed muscle. In course of time, also, the nerve-centres acquire the habit of adjusting their function to the changed conditions, and therefore the false projection of objects, with the giddiness which that entails, tends eventually to disappear.

6. *Altered Position of the Head.*—In order to avoid the

inconvenience and discomfort caused by the giddiness, diplopia, etc., the patient inclines his head in such a direction as not to call the paralyzed muscle into action—*i.e.*, the head is turned in the direction of the position of the paralyzed muscle. The position of the head, then, will vary with every different form of paralysis. Thus, if the symptoms occur when the eyes are turned to the right, the trouble is got over by turning the head to the right, so that the eyes themselves are directed to the left.

This unconscious adjustment was called *vicarious inclination of the head* by V. Graefe, because the muscles of the neck act as substitutes for the paralyzed eye muscle. As the patient looks in the direction of the action of the weakened muscle, it is comparatively easy to discover, from the inclination of the head, the nature of the paralysis. As Maddox puts it, '*the face indicates the physiological action of the paralyzed muscle.*'

If the face look	The muscle affected is either
To right,	R. extr. r. or L. intr. r.
To left,	L. extr. r. or R. intr. r.
To right and up,	R. supr. r. or L. infr. o.
To left and up,	L. supr. r. or R. infr. o.
To right and down,	R. infr. r. or L. supr. o.
To left and down,	L. infr. r. or R. supr. o.

(*From* MADDOX.)

7. *Diplopia* makes its appearance when the visual axis of one eye deviates from the correct position. *It is usually the first symptom which reveals to the patient the existence of his eye trouble.* The two images may be far apart, or they may be so close together that they overlap, in which case the object may appear not double, but as having merely a shadow. The diplopia occurs when the eyes are moved *in the direction of action of the paralyzed muscle,* the two images becoming more separated the farther the object fixed lies towards the limit of action of the affected muscle.* On reversing the move-

* This, however, is not always strictly true, as Maddox points out—*e.g.*, the superior rectus rotates the eye upwards and inwards, whereas in paralysis of this muscle the greatest diplopia is upwards and outwards.

ment, and turning the eyes in the opposite direction, the diplopia disappears.

Diplopia is always present in recent cases, but is not, of course, noticed when one eye is shut. *If the paresis of a muscle is slight, it may require an extreme movement of the eyes in the direction of the action of the failing muscle to disclose its presence.*

After a time the diplopia ceases to trouble, because the affected eye learns to 'suppress' its image. Both the false projection and the giddiness resulting from it disappear also as the nerve-centres become educated afresh to the altered

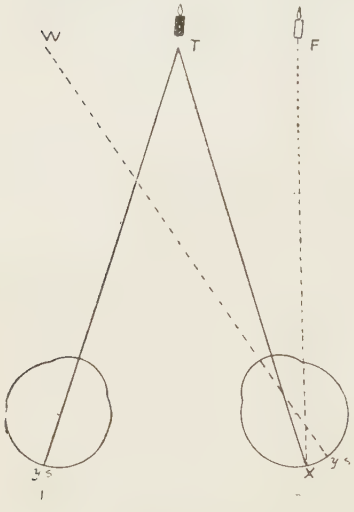


FIG. 100.—HOMONYMOUS DIPLOPIA.

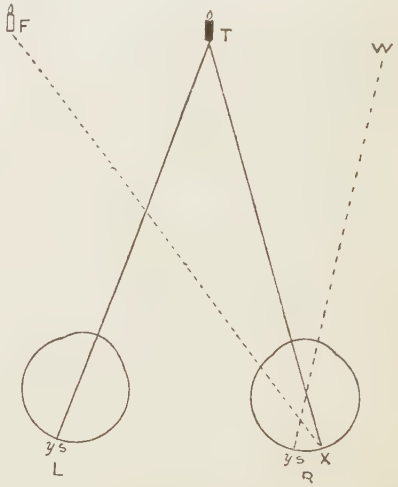


FIG. 101.—CROSSED DIPLOPIA.

conditions. The strabismus, however, tends, as a rule, to become more marked, owing to *contraction* of the antagonistic muscle.

The diplopia is explained by the fact that the two images of the object fixed do not fall upon 'identical points' (*vide* Fig. 90). The image falling upon the yellow-spot of the fixing eye is the 'true,' because it is referred to its proper position, while the other is the 'false,' because, falling upon an excentric part of the retina, it is in consequence referred to a wrong position. The 'false' image is less distinct than the 'true,' and, as a rule, moves from the 'true,' which remains stationary. The sensitiveness of the retina decreases progressively from the yellow-spot, and therefore the

lesser the deviation the more exact and sharp is the 'false' image and the more annoying the diplopia. For the same reason, the greater the deviation, the less exact and sharp is the 'false' image and the less annoying the diplopia.

The 'false' image of the deviating eye is always projected in the direction of the normal action of the affected muscle.

For example, if we suppose the *right external rectus* to be paralyzed (Fig. 100), the image in that eye will fall on the *inside* of the yellow-spot (at x), and therefore will appear to lie to the right of the image belonging to the left eye. The diplopia will accordingly be *homonymous*. If, on the other hand, the *internal rectus of the right eye* be paralyzed (Fig. 101), the image on the retina of that eye is formed on the *outside* of the yellow-spot (at x), and will be projected to the left of the actual position of the object, causing *crossed* diplopia.

In both cases, the greater the movement in the direction of the action of the paralyzed muscle, the greater will be the distance separating the two images; while, on the contrary, if the eyes be turned in the opposite direction, the distance will decrease, and the diplopia will ultimately disappear if the movement made be sufficient—that is, in a case of paralysis of the left external rectus, for instance, the diplopia will appear when the object is moved into the left half of the visual field, but will disappear when it is moved into the right half.

Rule.—When the optic axes cross, the diplopia is *not* crossed.

Homonymous diplopia	...	External rectus. Superior oblique. Inferior oblique.
Crossed diplopia	... ...	Internal rectus. Superior rectus. Inferior rectus.

In addition to lateral displacement, there may be also *vertical* and *torsional* displacement of the images, caused by one eye lagging behind the other in upward, downward, or diagonal movements of the eyeballs.

The *torsional* displacement is explained by the fact that an abnormal rotation of the eyes occurs in these diagonal positions, caused by the unopposed action of the oblique muscles, which under normal conditions should check this tendency of the paralyzed muscle.

With respect to the *false projection*, 'as V. Graefe has shown, the same principles apply to an abnormal rotation as to a defect in lateral movement' (Gowers).

It is in accordance with the direction of the eyes in which the double images are revealed, their situation with reference to each other, and the manner in which their distances apart become greater or less in the different positions of the eyes, that we are enabled to determine the seat of the paralysis.

'The line which separates the area of single or double vision varies in direction with each muscle, and corresponds with the position of the axis of the eyeball around which the globe moves when the muscle is in action; but the correspondence is seldom exact, on account of the co-operation of other muscles in certain positions' (Gowers).

When one muscle only is involved, it is in most cases comparatively easy to determine with exactness the seat of the paralysis from the nature of the diplopia; but when several muscles are implicated, there is often a complicated association of paralysis and spasm that may render the diagnosis extremely difficult.

Diagnosis of the Paralysis by the Diplopia Test.

We base the diagnosis of the affected muscle upon the nature of the diplopia. The patient is placed with his back to the window, or else taken into a dark room, and asked to follow with his eyes (*the head being kept still*) a lighted candle (the white handle of the ophthalmoscope will do equally well for all ordinary cases) held about 3 metres off, whilst it is moved upwards, downwards, to the right and to the left. In the first instance, the possibility of *monocular diplopia* (due to a 'double pupillary opening,' 'partial cataract,' etc.) should be eliminated by the observation that in paralytic strabismus the diplopia disappears when one eye is shut. It is a good plan to place a *red glass* in front of the *sound* eye, for by so doing we lessen the intensity of its image. Moreover, one image now being red and the other of its natural colour, the two can be more easily distinguished, and their relative positions better ascertained. Another advantage is that some patients are unconscious of double vision, and the coloured glass may make evident a diplopia the existence of which was hitherto unsuspected or had become forgotten, since in chronic cases the habit may have been acquired of suppressing the false image, the red glass reawakening it by contrast of colour.

The Affected Eye.—Suppose two images of the flame are seen, the one red and the other its natural colour, then, by rapidly closing and opening one eye several times in succession, the image which disappears and reappears must, of course, belong to this eye.

We next find out the *relative places* of the double images as the position of the candle-flame is changed, noting the following particulars:

(*a*) The exact position of the eyes in which the diplopia occurs.

(*b*) Whether the diplopia is *homonymous* or *crossed*.

(*c*) The amount of lateral separation.

(*d*) Whether the images are on the same or different levels.

(*e*) Whether the false image is *erect* or *tilted*.

Diplopia Chart.—The patient's answers are recorded on a chart (*vide* p. 101). This consists of a diagram ruled into *nine motor areas* by two vertical lines intersecting two horizontal ones. The true image is to be drawn in regular outline, and the false image represented in dotted outline.

If great accuracy is required, the exact displacement of the false image can be measured in degrees of arc by the Maddox glass rod and tangent scales.

VARIETIES OF OCULAR PALSIES.

Paralysis of Rectus Externus (Left Eye).

ANATOMICAL NOTE.—*The action of this muscle is to rotate the cornea directly outwards. It is supplied by the sixth nerve, which has a very long course, and* is more liable to disease than any of the other ocular nerves. *The nucleus of origin of the nerve is in the gray matter beneath the fasciculus teres, in the forepart of the floor of the fourth ventricle. It emerges from the lower border of the pons in front of the anterior pyramid of the medulla, and passes forwards to the inner wall of the cavernous sinus, where it lies to the outer side of the internal carotid artery. It enters the sphenoidal fissure between the two heads of the external rectus below the third and nasal nerves. In the orbit it supplies the external rectus on its* ocular *surface*.

SYMPTOMS.—Of all the extra-ocular muscles, the rectus externus is by far the most liable to isolated paralysis. Of 125 cases collected by A. Graefe, the external rectus was involved in 105.

The strabismus does not become revealed unless the eye be moved to the left of the median line. Thus the eyes can correctly fix an object held directly in front, but if the object be moved to the left of the median line *there is convergent squint of the left eye*, which becomes more pronounced in proportion as the object is moved farther to the left.

Homonymous diplopia is established upon looking towards the paralyzed side, the images being upright, parallel, and increasing in distance from one another as the object is moved farther to the left. If, whilst the head is kept fixed, the patient look diagonally upwards and outwards, the images appear to diverge at the uppermost portion of the field; but if he look downwards and to the left, the double images appear to converge at the lower portion of the field (*torsional displacement*)—a phenomenon due to the fact

that in looking upwards and to the left the right eye is rotated by the combined action of the internal rectus, superior rectus, and inferior oblique, the upper end of the vertical meridian of this eye being tilted inwards. The left eye, in order to look diagonally upwards and to the left, would require the combined action of the external rectus, the superior rectus, and the inferior oblique. But the first of these muscles is paralyzed, so that the left eye looks straight in front, with its vertical meridian upright. Under these circumstances identical points of the two retinæ cannot be stimulated, and therefore the image of the unaffected eye will appear erect because it falls on a normal part of the retina (*i.e.*, yellow-spot), whilst the image of the squinting eye will appear to lie obliquely, because it falls on an abnormal part of the retina (*i.e.*, on a part excentric to the yellow-spot). The same arguments apply when looking downwards and to the left. In order to avoid the diplopia, the head is often rotated slightly to the left side, so as not to call the affected muscle into action,

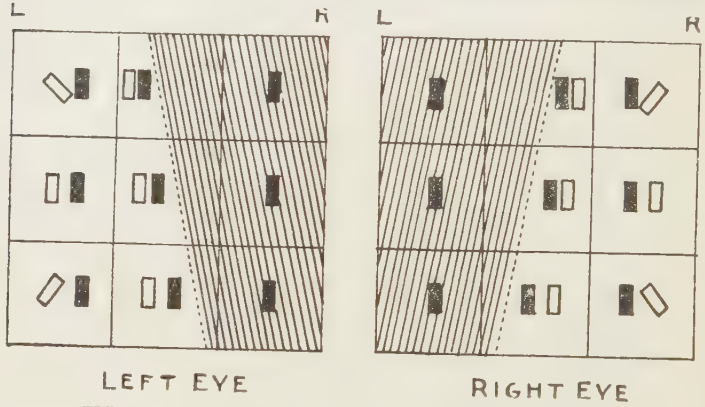


FIG. 102.—PARALYSIS OF THE EXTERNAL RECTUS.

(The shaded portion refers to those parts of the field of fixation in which there is no diplopia. The *false* image is represented in outline.) The diplopia is *homonymous* and horizontal, and exists only in the outer part of the field of fixation.

objects in front being fixed by turning the eyes to the right. Towards the limit of movement there may be jerky rotatory oscillations, caused by the unopposed action of the oblique muscles ('paralytic nystagmus').

Paralysis of the Muscles supplied by the Third Nerve.

ANATOMICAL.—*This nerve supplies all the external muscles of the eye (including the levator palpebræ superioris), except the external rectus and superior oblique. It also supplies all the internal muscles (ciliary muscle and sphincter iridis). The nucleus of origin is in the Sylvian gray matter beneath the aqueduct of Sylvius, its lower end being partially continuous*

with the nucleus of the fourth nerve. It emerges from the brain on the inner side of the crus cerebri immediately in front of the pons. It then courses through the outer wall of the cavernous sinus, and enters the sphenoidal fissure between the two heads of the external rectus, dividing into (a) an upper and (b) a lower branch.

(*a*) *The upper branch supplying—*

Levator palpebræ superioris;
Superior rectus;
Internal rectus.

(*b*) *The lower branch supplying—*

Inferior rectus;
Inferior oblique.

(*The offshoot to the inferior oblique also supplies the ciliary muscle and the sphincter iridis through the medium of the ciliary ganglion, of which it forms the motor root.*)

THIRD NERVE NUCLEUS.—*The order in which the fibres spring from this nucleus is as follows* from before backwards :

Ciliary muscle;
Sphincter iridis;
Internal rectus;
Superior rectus;
Levator palpebræ superioris;
Inferior rectus;
Inferior oblique.

(*The nuclei of the third, fourth, and sixth nerves are connected by commissural fibres, so that all the nerves to the ocular muscles are co-related at their origin.*)

SYMPTOMS.—The paralysis of the third nerve may vary both in distribution and degree, either affecting *all* the muscles *completely* or *partially*, or some completely and the others only partially, while some may escape altogether. In complete paralysis the upper eyelid droops, and cannot voluntarily be raised (ptosis). Upon the patient attempting to raise it, the occipito frontalis contracts vigorously, causing marked wrinkling of the skin of the forehead. The eyebrow on the affected side is higher than it should be. If the drooping eyelid be lifted by the finger, the globe is found to be almost immobile, but it can be moved outwards by the external rectus, and slightly downwards and inwards by the superior oblique. The pupil is of medium size, immobile, and it does not contract to light. The accommodation also is paralyzed. After a time the pupil tends to become larger, and secondary contracture of

the external rectus occurs, and thus there is developed a divergent squint, with crossed diplopia as a consequence.

To take an instance, let us assume the *left eye* to be affected. In looking towards the right, a divergent squint is manifested, accompanied by *crossed* diplopia. If the object looked at be moved upwards, the right eye will take the same direction, but the left eye will lag behind, and in addition there will be *crossed* diplopia, the *false* image being higher than the *true*, as the rays coming from the object will fall on the left retina *below* its yellow-spot, the image in consequence being projected *above* that falling on the yellow-spot of the right eye. Also, the upper end of the false image will be tilted towards the paralyzed side by the action of the superior oblique. If the object looked at be moved downwards, the false image, for a similar reason, will be projected below that of the right eye and tilted towards the true.

Paralysis of the Internal Rectus (Left).

ANATOMICAL.—*This muscle is supplied by the upper division of the third nerve. Its action is to rotate the eye directly inwards. Absolute isolated paralysis is very rare.*

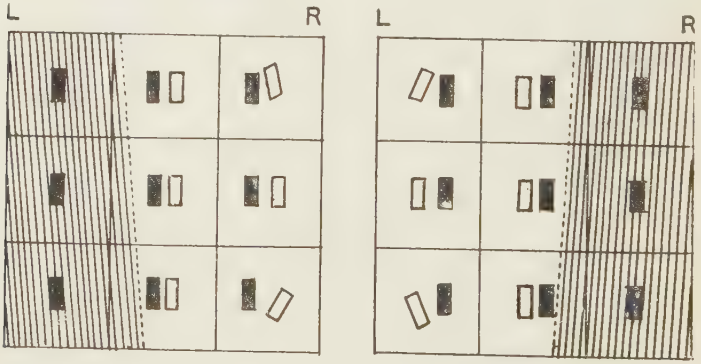


FIG. 103.—PARALYSIS OF THE INTERNAL RECTUS.

The diplopia is *crossed* and horizontal, and exists only in the inner part of the field of fixation.

SYMPTOMS.—If the object be moved from left to right, there is restriction of movement inwards, thus giving rise to *diver-*

gent squint, with *crossed diplopia* as a consequence. The *false* image is upright and parallel to the *true*, the lateral separation increasing in proportion as the object is moved further to the right. Both the images remain upright and *parallel in looking vertically upwards and downwards*, but if the eyes be directed diagonally upwards and inwards, the *false* image will be on a plane slightly higher than that occupied by the *true*, and will slant inwards. On the other hand, if the eyes be directed diagonally downwards and inwards, the false image will appear lower than the true, and will slant outwards. The face is turned in the direction of the sound eye.

Paralysis of the Superior Rectus (Left).

ANATOMICAL.—*This muscle is supplied by the upper division of the third nerve. Its action is to rotate the cornea upwards and somewhat inwards, and to incline the vertical meridian inwards.*

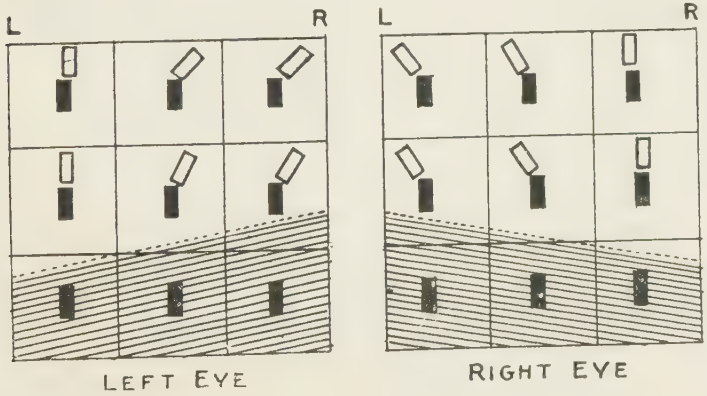


FIG. 104.—PARALYSIS OF THE SUPERIOR RECTUS.

The diplopia is *crossed* and vertical, and exists only in the upper part of the field of fixation.

SYMPTOMS.—The incompetence of the muscle becomes evident only when the eye is moved *above the plane of the horizon*, so that the diplopia occurs only when the patient looks up. A divergent squint is developed when the eyes are directed above the horizontal plane. The head is thrown back, and inclined towards the sound side, so as to avoid the diplopia occasioned by looking upwards.

The diplopia is *crossed* and vertical, and is noticed only in

the upper part of the field of fixation. The double images are not on the same level, the false image lying above and to the right of the true image. The vertical displacement of the false image increases as the eye is turned to the left, but decreases as the eye is turned to the right. The upper end of the false image is tilted to the right, this obliquity increasing on adduction.

Paralysis of the Inferior Rectus (Left).

ANATOMICAL.—*Supplied by the inferior division of the third nerve. Its action is to rotate the cornea downwards and somewhat inwards, and to tilt the upper end of the vertical meridian outwards.*

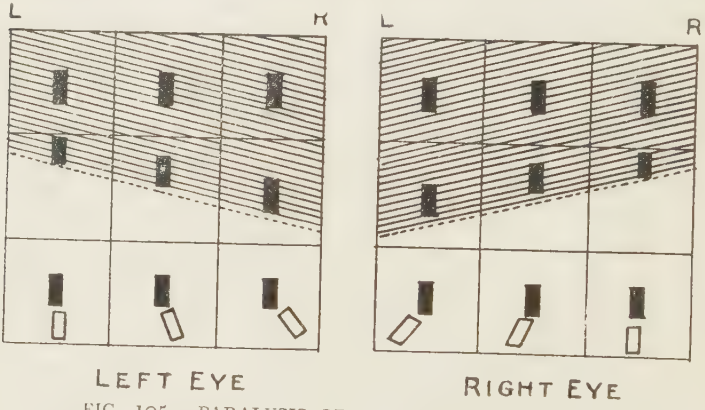


FIG. 105.—PARALYSIS OF THE INFERIOR RECTUS.

The diplopia is *crossed* and vertical, and exists only in the lower part of the field of fixation.

SYMPTOMS. — Paralysis of this muscle gives rise to symptoms just the reverse of those due to failure of the superior rectus, the defective action being observed solely in movements below the horizon. The diplopia, therefore, is noticed only in looking down. The double images are crossed, the *false* image being below the level of the *true*, with its upper end tilted towards it. Upon directing the eyes downwards and towards the paralyzed side, the vertical displacement increases, but the tilting decreases. The head is inclined downwards and towards the right. When an attempt is made to look down, the upper eyelid remains stationary.

Paralysis of the Superior Oblique (Left).

ANATOMICAL. — *This muscle is supplied by the fourth nerve, the nucleus of origin of which is in the Sylvian gray matter beneath the floor of the aqueduct of Sylvius. It emerges from the brain at the inner border of the superior peduncle of the cerebellum, just behind the corpora quadragemina. It is very thin and of considerable length. Coursing round the crus cerebri, the nerve passes forwards in the outer wall of the cavernous sinus, and enters the orbit through the sphenoidal fissure, and supplying the superior oblique on its* orbital *surface. Its action is to roll the cornea downwards and outwards, and to incline the vertical meridian inwards.*

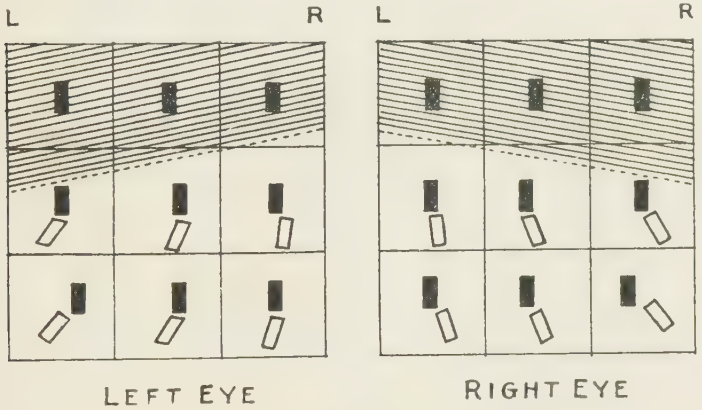


FIG. 106.—PARALYSIS OF THE SUPERIOR OBLIQUE.

Diplopia exists only in the lower part of the field, and is *homonymous* and vertical.

SYMPTOMS.—The deviation of the eye when this muscle is paralyzed is so slight that its detection is very difficult, or even impossible, by objective examination. *Actually*, the eye deviates upwards and slightly inwards, with the upper end of the vertical meridian tilted outwards. There is restriction of movement downwards, especially when looking downwards and towards the affected side.

Objects in the lower half of the field of vision appear double and distorted, so that there is great difficulty in moving about, more particularly in going down a flight of stairs, each of which appears to be duplicated, with the result that the patient does not know which to select. The dividing-line between the fields of single and double vision is not horizontal, but declines obliquely from right to left. If

the patient look *above* the horizontal plane there is no diplopia, but, on looking below it, there is well-marked diplopia, having the following characteristics: it is confined to the lower part of the visual field; it is homonymous, the *false* image being the lower, especially on looking inward, and having the upper end tilted towards the *true*, particularly on looking outwards. The vertical displacement increases, and the tilting of the false image decreases, if the eyes are turned downwards and towards the nose. The head is inclined forwards, and towards the unaffected side, leaning toward the shoulder of the sound side, so as to avoid the diplopia by bringing objects as much as possible into the upper and left part of the field of vision. The detection of paralysis of this muscle is often very difficult, and if the other eye cannot be moved downwards, its discovery may be impossible.

Paralysis of the Inferior Oblique (Left).

ANATOMICAL.—*This muscle is supplied by the inferior division of the third nerve. Its action is to roll the cornea upwards and outwards, and to incline the vertical meridian outwards.*

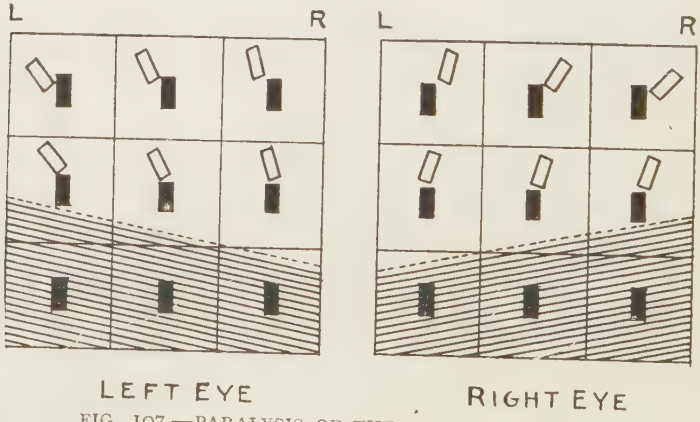


FIG. 107.—PARALYSIS OF THE INFERIOR OBLIQUE.

The diplopia is vertical and generally homonymous, and exists only in the upper part of the field.

Paralysis of this muscle alone is very rare, being found in but 2 of the 145 cases collected by A. Graefe. There is

restriction of movement *upwards* and towards the affected side, the eye being turned downwards with the vertical meridian tilted towards the nose. The diplopia is vertical and generally *homonymous*, and only appears *on looking up*. The false image is higher than the other, with its upper end tilted towards the temple, the tilting being greatest in looking upwards and outwards, the vertical displacement in looking upwards and inwards. The head is inclined backwards, and leans towards the right.

Rate of Frequency of Paralysis of Isolated Muscles.

Of the 145 cases collected by A. Graefe, the rate of incidence was as follows:

External rectus	105
Superior oblique	52
Inferior rectus	10
Superior rectus	9
Internal rectus	4
Inferior oblique	2

The frequency of isolated paralysis of the first two is to be ascribed to the fact that each is supplied by a separate nerve which comes straight off from the brain, and has a long and exposed course.

Site of the Lesion.—The lesion may be anywhere between the cortical motor centre and the responding muscle. It is convenient to distinguish between (*a*) *intra-cerebral* and (*b*) *extra-cerebral* lesions. The various links in the neuro-muscular chain are:

Intra-cerebral ...
- (i.) Cortex.
- (ii.) Association or co-ordination centres in optic thalami, corpora quadrigemina, and pons.
- (iii.) Nuclei of origin in aqueduct of Sylvius and floor of fourth ventricle.
- (iv.) Origin from base of brain.
- (v.) The fibres connecting (i.), (ii.), (iii.), (iv.), and (v.).

Extra-cerebral ... (vi.) The nerve itself
- (*a*) Intra-cranial.
- (*β*) Sphenoidal fissure.
- (*γ*) Intra-orbital.

If the lesion be (*a*) *intra-cerebral*, it may be due to isolated disease of the *nuclei* (nuclear ocular palsy) or a *degeneration* in connection with

tabes dorsalis, *disseminated paralysis*, etc. It may also result from a *hæmorrhage*, *thrombosis*, or *embolism*.

Intra-cerebral disease rarely causes paralysis of isolated ocular muscles, and accordingly, if there be a paralysis of individual muscles, intra-cerebral disease can, as a rule, be excluded.

The diagnosis of the intra-cerebral lesion must be made upon the collateral symptoms—*e.g.*, implication of other nerves, loss of memory, headache, etc.

If there be *complete* loss of power of any of the muscles, unassociated with other forms of paralysis, the cause is very rarely intra-cerebral. On the other hand, if the loss of power is but partial, the lesion is usually intra-cerebral. This, no doubt, depends upon the fact that in the brain the nerve fibres separate out from one another, so that the lesion would require to be very extensive to involve them all, in which instance other cranial nerves would be implicated, while in the case of the nerve itself after it has left the brain, a comparatively small lesion would be sufficient to involve *all* its fibres.

If the lesion be (*b*) *extra-cerebral*, a common cause is injury, especially when in the neighbourhood of the sphenoidal fissure. *Neuritis* is another frequent cause, due most likely to tertiary syphilis, and in a lesser degree to alcohol. 'Within the skull it is generally secondary to meningitis' (Gowers). The nerves may also be compressed by new growths or aneurism, more particularly when situated in the cranial cavity. 'Tumours of the nerves themselves are rare; neuromata are almost unknown' (Gowers).

Prognosis is bad unless the disease be due to a local neuritis, in which case it is good. If recovery does not take place, the opposing muscle often becomes contracted, a permanent squint thus being established. In cases which have lasted a long time, the muscles of the neck may also become permanently contracted, from the habit of inclining the head to one side.

Treatment (to avoid the diplopia).—This resolves itself into treatment of the cause. As a general principle, it may be said that rest is indicated at the onset, both for the eyes and the body, and, preferably, rest in bed. If the patient cannot lie up, a shade may be worn over the affected eye, or a prism (not stronger than 4°) be used to correct the discomfort of the diplopia, but, as it can only do so for one position of the eyes, it is but rarely used for this purpose.

In syphilis the ordinary treatment must be followed. 'In most cases of local neuritis, indeed, whether syphilitic or not, mercury is probably the most efficient agent we possess' (Gowers).

In *acute* cases, a blister behind the ear if the disease be intra-cranial, or on the temple if it be intra-orbital, is often very useful in restoring the power of the affected muscle.

'Electricity has been recommended and employed in the treatment of these paralyses, but its influence is not great' (Gowers). It should never be employed during the acute stage, but when the disease has become chronic. The constant current (about 3 milliampères), with the cathode applied to the nape of the neck and the anode over the affected muscle (cocaine having been previously instilled), occasionally gives good results. The current can also be administered through the closed lid.

It is a good plan, in some cases, to exercise the failing muscle by prescribing a prism *which nearly corrects the diplopia*, in this way exciting the weakened muscle into action. After a time, a prism of less power can be ordered, and so on.

If the paralysis has lasted a long time, and the case seems incurable by other methods of treatment, tenotomy of the opposing muscle, advancement of the affected one, or a combination of both these operations, may be performed in order to remove the *disfigurement of the squint*, but the return of binocular single vision is, under these circumstances, very unlikely. This treatment, when applied to the internal and external recti, is to be regarded as promising a fairly good result, but in the case of the superior and inferior recti it is much less satisfactory, while in that of the oblique muscles the results are so distinctly unsatisfactory that the operation is certainly not justified.

Paralysis of the Internal Muscles of the Eye.

There are four possible varieties:

1. Paralysis of the ciliary muscle, causing loss of accommodation (*cycloplegia*).
2. Failure of the pupil to contract to light (*reflex iridoplegia*).
3. Failure of the pupil to contract in response to accommodation (*accommodation iridoplegia*).
4. Loss of the reflex dilatation of the pupil to stimulation of the skin (*cutaneous iridoplegia*).

Combinations of these paralyses often occur. If all the internal muscles are affected, the term *ophthalmoplegia interna* is applied.

The *diphtheric toxin* is the commonest cause of paralysis of the ciliary muscle, which is always symmetrical. It may also come on after *influenza*, and sometimes follows *concussion of the brain*. Apart from these, the chief cause of these isolated palsies are degenerations in the central nervous system, such as those associated with tabes dorsalis, etc. 'When the reflex loss is due to central degeneration, the ciliary muscle is usually unaffected, and the pupils contract to accommodation' (Gowers).

APPENDIX

Regulations for Admission into the Services.

Commissions in the Army.

The vision of each eye must be not less than $\frac{6}{36}$ *without glasses*, provided that with his correction the vision of one eye can be brought up to $\frac{6}{6}$ and $\frac{6}{12}$ with the other.

Commissions in the Royal Navy.

The vision of each eye must be $\frac{6}{6}$ *without glasses.*

Indian Civil Service.

The vision of one must be $\frac{6}{6}$, and that of the other not less than $\frac{6}{9}$, *with* or *without glasses*. A nebula is allowed if the vision is not less than $\frac{6}{12}$, but the other eye must be $\frac{6}{6}$ with or without glasses.

Department of (Indian) Public Works, Forests, Survey, Telegraph, Railways, Factories, Police.

The vision of one eye must be $\frac{6}{6}$, and that of the other not less than $\frac{6}{9}$, *with* or *without glasses*, provided that myopia does not exceed 2·5 D.

Myopic astigmatism is not to exceed 2·5 D. of combined spherical and cylindrical correction.

Hypermetropia is not to exceed 4 D., of hypermetropic astigmatism ; the combined lenses not to exceed 4 D.

A nebula is allowed if the vision is not less than $\frac{6}{12}$, but the other eye must be $\frac{6}{6}$.

INDEX

Accommodation, 43
Acquired hypermetropia, 102
Acuteness of vision, 38
Alternating strabismus, 182
Ametropia, 95
Amplitude of accommodation, 47
Angle alpha, 35
Angle gamma, 36
Angle visual, 38
Anisometropia, 145
Anterior focus, 31
Apparent strabismus, 177
Army regulations, 211
Asthenopia, 152
Astigmatism, 125
Atropine, 78
Axis, optic, 34
,, principal, 9
,, secondary, 9

Biconcave lenses, 14
Biconvex lenses, 9
Bifocal lenses, 149
Binocular vision, 153

Cardinal points, 13
Centrads, 7
Centre of rotation, 35
Ciliary muscle, 44
Civil service regulations, 211
Colour sense, 38
Concave lenses, 14
Concomitant squint, 176
Conjugate focus, 10
Convergence, 49
Convergent squint, 182
Convex lenses, 9
Crescent, congenital, 89
,, myopic, 118
Crossed cylinders, 21
Cyclophoria, 164
Cycloplegia, 209
Cylindrical lenses, 19

Decentration of lenses, 17
Detachment of retina, 118
Deviation, primary, 176
,, secondary, 177
Dioptre, 16
Diplopia, 154
Diplopia test, 198
Direct ophthalmoscopic examination, 65
Distant test type, 39
Divergent squint, 188
Dynamic refraction, 34

Emmetropia, 34
Erect image, 11
Esophoria, 164
Exercises, orthoptic, 186
Exophoria, 164
Extra ocular muscles, 160

False projection, 193
Far-point, 46
Focal interval of Sturm, 126
Formation of retinal image, 28
Form sense, 38
Fundus oculi, 85

Glasses
,, biconcave, 14
,, biconvex, 9
,, cylindrical, 19
,, pantoscopic, 149
,, tinted, 150
Glaucomatous cup, 87
Goggles, 150

Herring's drop test, 157
Heteronymous diplopia, 154
Heterophoria, 163
Homocentric, 2
Homonymous diplopia, 154
Horopter, 154
Hyperesophoria, 164
Hyperexophoria, 164
Hypermetropia, 95
Hyperphoria, 164
Hypophoria, 164

Images, formation of, 11
Indian services, 211
Indirect method, 62
Insufficiency, 163
Inverted image, 11
Inverted ophthalmoscopic image, 62
Irregular astigmatism, 126
Iridoplegia, 209

Jaeger's test-types, 45
Javal's orthoptic exercises, 186

Landolt, 36
Latent hypermetropia, 99
Latent squint, 163
Lenses, 8
Light sense, 38
Line of vision, 35
Line of fixation, 35

Maddox's rod-test, 167
Malignant myopia, 112
Malprojection, 193
Manifest hypermetropia, 99
Measurement of squint, 179
Metre angle, 49
Microphthalmos, 99
Mirrors, 24
Mixed astigmatism, 128
Monocular vision, 156
Motor field, 158
Muscle, ciliary, 44
Muscular asthenopia, 163
Myopia, 106
Myopic astigmatism, 128

Naval services, 211
Near-point, 45
Neurasthenic, 173
Neutralization of lenses, 22
Nodal points, 30
Numbering of lenses, 16

Oblique muscles, 160
Ocular vertigo, 194
Opaque nerve fibres, 93
Ophthalmoscope, 57
Optic axis, 34
Optical centre, 9
Optics, 1
Orientation, 157
Orthoptic exercises, 186

Pantoscopic spectacles, 149
Paralysis of eye muscles, 190
Perimeter, 53
Periodic squint, 177
Periscopic glasses, 150
Physiological heterophoria, 162
Plane mirror, 24
Points, cardinal, 13
Position of spectacle glasses, 147
Posterior staphyloma, 118
Presbyopia, 140
Primary deviation, 176
Principal points, 30
Prisms, 5
Prism-dioptres, 7
Punctum proximum, 45
Punctum remotum, 45
Pupil in accommodation, 45
,, paralysis of, 209

Railway regulations, 211
Range of accommodation, 46
Reduced eye, 32
Reflection, 24
Refraction, 3
Regulation for services, 211
Regular astigmatism, 127
Retina, 93
Retinal image, 28
Retinoscopy, 74
Rod test, 167

Scotomata, 55
Secondary deviation, 177
Snellen's test types, 39
Spasm of accommodation, 100
Spectacles, 147
Staphyloma, posterior, 118
Stenopaic slit, 150
Stereoscope, 186
Stereoscopic vision, 156
Strabismometer, 179
Strabismus, 175
Sturm, focal interval of, 126

Table for presbyopia, 140
Tangent strabismometer, 179
Tenotomy, 188
Test-types, 39

Virtual focus, 10
Vision, acuteness of, 38
Visual angle, 38

Baillière, Tindall and Cox, 8, Henrietta Street, Covent Garden, W.C.

JAN 3- 1907

BOS
DEC 10
SEC
DEC 10 1906
28.F.39.
The refraction of the eye and t1903
Countway Library BDR8832
3 2044 045 477 627

28.F.39.
The refraction of the eye and t1903
Countway Library BDR8832
3 2044 045 477 627